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Chapter 1 Introduction to the Nanomanipulator System

This chapter provides basic information about the Nanomanipulator System and its manufacturer.

About the System

The Nanomanipulator Systems are positioning and testing tools for micro- and nanoscale research and development applications. This line of products is part of a family of NanoWorks™ tools offered by Zyvex.

All systems come with an easy-to-use joystick and illuminated keypad to provide an unparalleled degree of control. Interchangeable NanoWorks tools such as the NanoEffector™ or the MicroEffector™ series, provide options to enhance your range of testing—whether your aim is to study meso-, micro-, nano-, or molecular based structures.

About the Manufacturer

Founded in 1997, Zyvex is the first molecular nanotechnology company. Our mission is to become the leading worldwide supplier of tools, products, and services that enable adaptable, affordable, and molecularly precise manufacturing.

About this Manual

The Nanomanipulator System User Manual provides system specifications, descriptions of user controls, and detailed procedures for using the system. Users who are familiar with their micro- and nanoscale application can use this manual to learn the basics of operating the Nanomanipulator System.

Contact information

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Chapter 2: Terminology Guide

This chapter defines the acronyms, abbreviations, and terms used in this manual.

Acronym/Abbreviation/Term	Definition
AC	Alternating Current
AFM	Atomic Force Microscope
APR	All PZT Reset
BNC	Bayonet Neill Concelman connector
CA	Coarse Axis (Extended Range Axis Motion)
CCD	Charge Coupled Device
CNT	Carbon Nanotube
Corona Discharge	A discharge of electricity on a conductor due to the ionization of the surrounding air by the high voltage; occurs in the corona region of pressure
CPP	Current Positioner Preset
DAC	Data Acquisition Card
EBID	Electron Beam Induced Deposition
FA	Fine Axis
FIB	Focused Ion Beam
GUI	Graphical User Interface
HF	Hydrogen Fluoride
HV	High Vacuum
IC	Integrated Circuit
IPA	Isopropyl Alcohol
KITE	Keithley Interactive Test Environment
LCD	Liquid Crystal Display

Acronym/Abbreviation/Term	Definition
LED	Light Emitting Diode
MEMS	Microelectronic Mechanical Systems
MOSFET	Metal-Oxide Semiconductor Field-Effect Transistor
Motor	Piezo Motor
MUMPS	Multi-User MEMS Process
MUX	Multiplexer
MWNT	Multi-walled Nanotube
PC	Personal Computer
PTFE	Polytetrafluoroethylene
PWM	Pulse Width Modulation
PZT	Plumbum Zirconate Titanate (Piezo-electric element)
RS232	Recommended Standard 232 (EIA's standard for Serial Data Communication)
RST	Reset
SEM	Scanning Electron Microscope
SLD	Slip Stick Motion Drive
SR	Speed Rate
TEM	Transmission Electron Microscope
TV	Television
UHV	Ultra-High Vacuum
USB	Universal Serial Bus

Chapter 3: Safety Precautions

Electrical Shock

Harmful electrical shock may result from the following:

- Powering up the system when there is known or suspected damage to the system.
- Powering up the system if any of the cabinet covers or panels are removed.
- Connecting to outlets whose line voltage does not match the voltage rating on the controller unit.
- Operating the system when it is not properly grounded.
- Touching the system head while the controller is powered on.
- Touching the system wiring while the connectors are disconnected.

Fire Hazards

Fire may result from using the system or controller cabinet in the presence of flammable gases, fumes, or liquids.

Damage to the System

Damage to the system and corresponding loss of the manufacturer's warranty may result from the following:

- Allowing condensation to form on the equipment.
- Using excessive force or sideways motion to connect or disconnect connectors, especially NanoEffectors as the piezo-electric elements are brittle.
- Subjecting the equipment to external shocks.
- Blocking the system ventilation and fan on the cabinet.
- Substituting or modifying parts without written authorization from Zyvex.
- Running the system in an environment outside the ambient temperature range.
- Not using proper grounding prior to touching electronic components in the system. The outside of the cabinet may be used for this.
- Handling the system head and in-vacuum cabling without gloves.
- Using an unauthorized storage device or packaging.
- Turning the nanomanipulator assembly more than 1/4 of a turn with your equipment's sample stage.

- Exposing the system to rain, snow, or dust.

Special Precaution During Pumpdown and Venting

During system pumpdown and venting for systems used in UHV environments, the chamber goes through a corona region of pressure where, if the electronics are still on, severe damage can occur to the piezo-electric elements, motor, and electronic components of the system. Make sure all of the nanomanipulator's high voltage amplifier outputs are turned off when pumping down and venting the vacuum chambers, respectively. There are two methods to do this:

- From the GUI, click on the "All PZT RST" button.
- From the keypad, press on the "PZT RST" button.

Note: As an extra level of security, the nanomanipulator systems include a Safety Interlock to continuously monitor the vacuum level and to report the data to the control systems. The control system automatically resets all the high driving voltages to the system's actuators and inhibits actuations. For a detailed description of the Safety Interlock, see Chapter 5, "Safety Interlock" on page 25. Although this safety measure is in place, users should make sure to follow the steps above.

Other Safety Notes

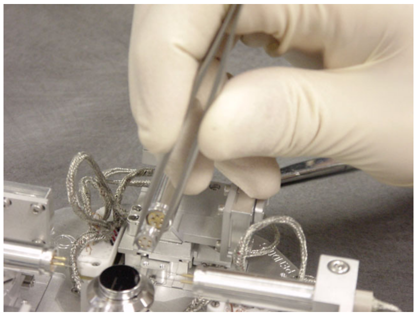
- Although most of the components are compatible with an ultra-high vacuum (UHV) environment, the nanomanipulator systems are designed to be compatible to 10^{-6} Torr. Heating the surface of the system to remove moisture and increase vacuum (known as "baking out") is not advised. For more information, see Chapter 6, "Cleaning" on page 29.
- If the equipment is exposed to hazardous materials, properly decontaminate the system after using it and before storing it in its dry box.
- Only trained Zyvex personnel are allowed to service the system.
- For your equipment's safety precautions, please consult the manufacturer's instructions.
- Users must read and understand the manual prior to using the Nanomanipulator System.

Chapter 4: Quick Reference Guide

This chapter outlines the procedures you will follow essentially every time you use the nanomanipulator system. You can use this chapter as a quick reference guide or checklist. For more detailed information on installation, setup, and removal of the any of the systems, please see Chapter 7: “Installation and Setup” on page 31.

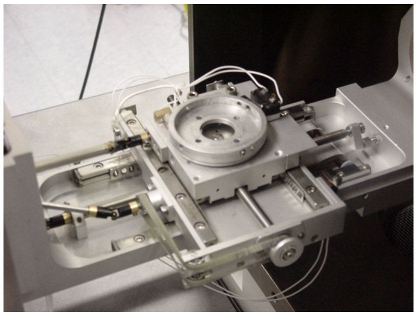
To prepare the experiment:

1 Place the NanoEffectors onto the positioners and a sample onto the sample stage, if applicable. If you have any special NanoEffectors or samples to place on one of the positioners, place them on positioner 1, so that it will be easier to get a sense of direction in your equipment’s view.



To mount the head assembly into your equipment:

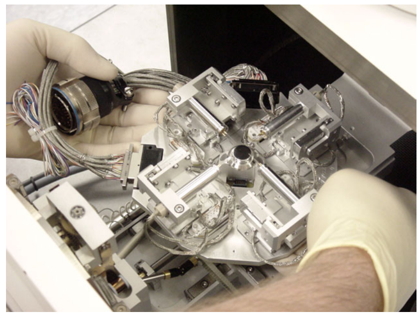
1 For UHV applications, open the chamber door.



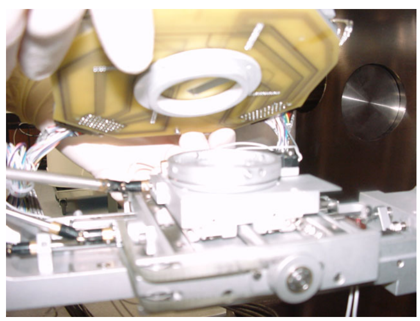
2 Ensure that the stage mount is at its lowest position, so the head assembly will clear the lens and/or beams.

3 Retract the set screws on the adapter riser of your equipment.

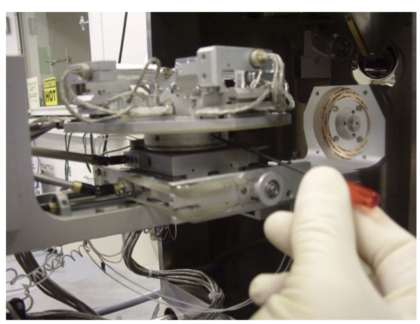
4 Use both hands to orient the head assembly so that the connectors face the feedthrough port. Orienting it this way minimizes tension on the wiring and makes it easier to attach the connector.



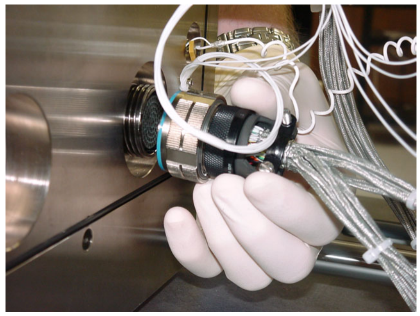
5 Align the adapter ring on the bottom of the head assembly to the adapter riser on your equipment.



6 Finger tighten the set screws at the base of the head assembly.



7 Connect the in-vacuum connector to the vacuum side electrical feedthrough.



Note: This connector is keyed and will only connect to the vacuum side electrical feedthrough one way. As you turn the connector, it clicks and is fully connected after one full rotation (360 degrees).

8 Square the head assembly using the stage controls.

CAUTION: Do not rotate the system more than 1/4 of a turn. Doing so may damage one of the connectors by causing too much tension in the wiring.

9 For UHV applications, ensure that the head assembly will clear the lens or beams and that the wiring will clear the door before you close the chamber door.

10 Close the chamber door, if applicable.

11 Pumpdown the system, if applicable.

Note: The actuators require high driving voltages. During pumpdown and venting, the inside chamber goes through a corona region[1] of pressure. If the system's driving voltages to the actuators are on at this time, severe damage to the actuators can occur. To prevent this damage, the system includes a Safety Interlock to continuously monitor the vacuum level and report the data to the main control system, which automatically resets all the high driving voltages to the system actuators and inhibits actuations. For a detailed description of the Safety Interlock, see Chapter 5: "Safety Interlock" on page 25.

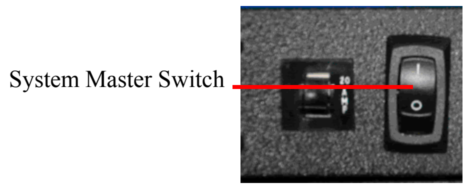
12 Connect the external wiring harness to the air side of the vacuum electrical feedthrough.

Note: Before you start imaging, you may want to adjust the Z height of the system to within the optimal working distance of your application.

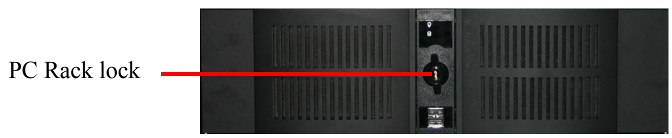
1. A region of pressure in which the mean free path allows for collision and ionization of particles in the presence of an electric potential. Such ionization can cascade into full dielectric breakdown, resulting in the creation of a plasma. This plasma will act as a path between conductive surfaces, in effect, creating a short-circuit. Catastrophic damage can result from such shorting. For this reason, all electrical components should be switched off before bringing the system to vacuum and before venting the chamber to atmospheric pressure.

To power-on the Nanomanipulator System:

1 Turn on the system master switch, located at the top left of the cabinet.



2 Rotate the PC Rack lock clockwise (1/4 turn), and open the door of the rack to expose the PC components and Switch.



3 Press the PC Switch once.

The PC Power LED should now be lit.

4 Make sure the LCD monitor is on, and wait for the system to boot up and display the Windows login.

5 Open the application (usually found in the Start Menu under the Programs folder and then under the Zyvex folder).

6 Enter your user name and password. The software retrieves your saved user configuration.

For further instructions on using the System software, see Chapter 8: “Using the System Software, Keypad, and Joystick Controls” on page 43.

To turn on the system actuators and driving electronics:

1 Locate the Power Supply Rack directly below the Drawer.

Power Supply Switch

2 Turn on the Power Supply Switch.

The LEDs on this rack should now be lit.

Determining where your NanoEffectors are:

1 Check the software and make sure you are in local coordinates.

2 If your equipment’s imaging system does not have a CCD view, please refer to your equipment’s documentation. If it does have a CCD view, continue with Step 3.

3 In the CCD view (TV Mode), look at your sample stage and find a point of reference, or a part of the sample that you are interested in.

4 View an image at low magnification, looking for the point of interest.

5 Return to TV mode, and begin by finding positioner 1. Select P1 (P1 button is lit blue on the keypad), actuate one of the axes button--X, Y, or Z (lit white on the keypad) while in the extended range mode (FA/CA button should not be lit)--and the Fast button (FST button on the keypad is lit green) motion, and move with the turbo button pressed. This will make it easier to detect the motion with the naked eye.

Approaching the sample:

1 Raise the positioners so that the probes or other NanoEffectors clear possible obstructions like the sample stage when they are brought in towards the center.

2 If there is a stage mounted, move the stage to ensure that the probes will clear.

3 Check that you are in extended range motion mode (the FA/CA button on the keypad should not be lit).

4 To lift the probes, actuate in the positive Z direction (turning the joystick counterclockwise), and push the Z button to enable the Z axis (Z button on the keypad should be lit white).

5 Bring the probes toward the center stage. Because you are in local coordinates mode, you will do this by moving in the positive Y direction for all positioners. To do this on any of the positioners, activate the Y button on the keypad (lit white) and then push the joystick up.

6 Return to your equipment's imaging system, and find one of your NanoEffectors.

Once you find one probe, finding the rest of the probes is easier because you can simply move the viewing area. Try following the edge of the sample stage or your sample carrier until you have gone 90 degrees, and bring in each of your probes further toward the center. Again try not to rotate the assembly unless you absolutely have to and even then, no more than 1/4 of a turn. Remember to turn it back once you have finished.

7 Bring all positioners into one image while you're still at low magnification.

8 Begin your experiment.

Chapter 5: System and Equipment Specifications and Descriptions

This chapter describes the equipment for the Nanomanipulator System.

Systems Description

The Nanomanipulator System consists of the following five subsystems:

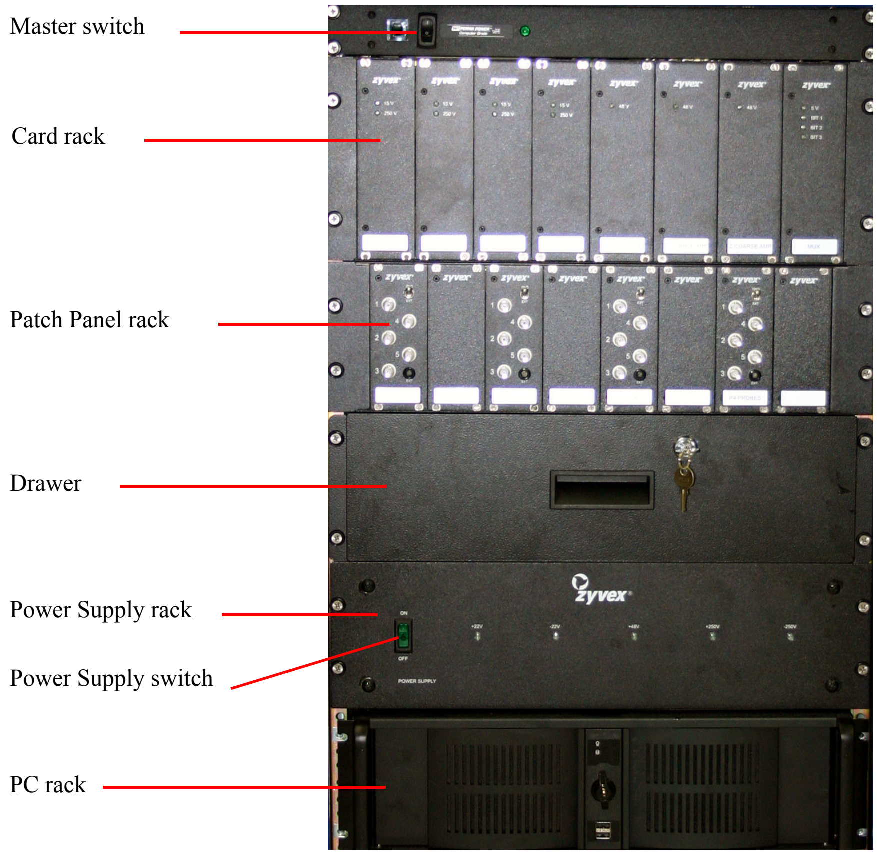
- Controller cabinet
- Control panel (keypad and joystick)
- Graphical User Interface (GUI)
- Nanomanipulator head assembly with positioners for your specific application (The current base plate can hold up to four positioners and a sample stage.).
- Feedthrough assembly

In addition, Zyvex currently offers two types of accessories that complement the Nanomanipulator System:

- NanoEffector/MicroEffector Series of probes and tools—robotic probes and tools for manipulation and electrical characterization, microgrippers, microactuators, or thermal sprayers for electron beam deposition.
- Nanostructure Portable Carrier Kit—consists of nanostructure carriers with TEM transfer carriers

For more information about these accessories, please contact Zyvex.

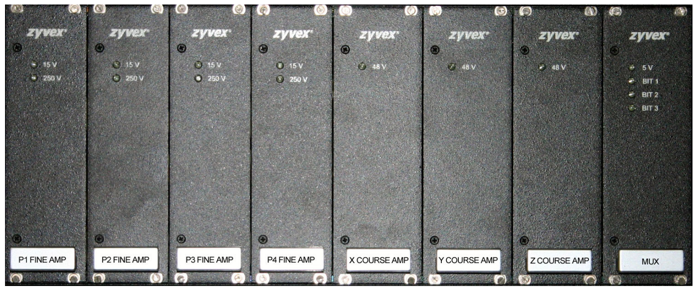
Controller Cabinet



The controller cabinet houses the following components (from top of cabinet):

- Card rack
- Patch Panel rack
- Drawer
- Power Supply rack
- PC rack

Card rack



The card rack holds all the electronics that drive the actuators. The cards are listed below (from left to right):

— **P1 Fine Amp card** holds the driving amplifiers for Positioner1's fine axes (if applicable).

— **P2 Fine Amp card** holds the driving amplifiers for Positioner2's fine axes (if applicable).

— **P3 Fine Amp card** holds the driving amplifiers for Positioner3's fine axes (if applicable).

— **P4 Fine Amp card** holds the driving amplifiers for Positioner4's fine axes (if applicable).

— **X Coarse Range Amp card** holds the X-axis extended range controllers.

— **Y Coarse Range Amp card** holds the Y-axis extended range controllers.

— **Z Coarse Range Amp card** holds Z-axis extended range controllers.

— **MUX card** is the multiplexer card and acts as a switch for the extended range actuators.

The cards have LEDs labeled by voltages. The LEDs indicate the status of the power supplies to the indicated subsystem.

Patch Panel rack

ground switch

The Patch Panel rack holds four Patch Panel cards, one card for each of the positioners the head can hold. Each Patch Panel card has five BNC connectors labeled from “1” to “5.” These BNC connectors are internally connected to the individual sockets on the end of the fine positioning assembly of a positioner. The intent of the Patch Panel card is to provide an interface for the user to make direct electrical connection to any of the five sockets for NanoEffectors on a positioner.

Each Patch Panel card has a ground switch which can be used to isolate the ground from the cabinet. Toggling the switch to the up position grounds all the BNC connectors of the Patch Panel card to the cabinet.

The patch panel cards are labeled as follows:

— **P1 Panel** (NanoEffector connections panel for Positioner1)

— **P2 Panel** (NanoEffector connections panel for Positioner2)

— **P3 Panel** (NanoEffector connections panel for Positioner3)

— **P4 Panel** (NanoEffector connections panel for Positioner4)

Note: To facilitate high sensitivity measurements by minimizing noise inherent from cabling and the ambient surroundings, users may install additional equipment, such as a breakout box. The breakout box is connected to the system via the vacuum feedthrough connector. For more information, please contact Zyvex.

Drawer

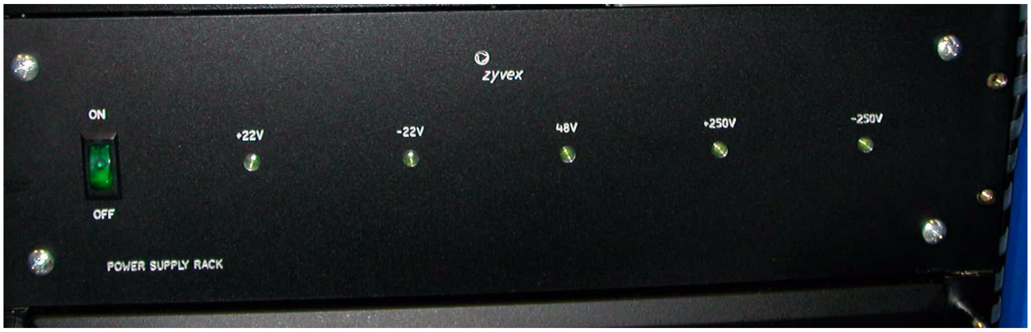
A drawer is provided inside the cabinet for storing supplies such as probes and other experiment media. To prevent moisture build-up on the head assembly, store the system in a dry box before placing it in the drawer. If a dry box isn’t available, then store the system in its original box with foam inserts, bearing in mind that this will increase the pumpdown time on a UHV application.

PC rack

The PC rack holds the computer used by the System. Accessories for this rack are the monitor, keyboard, and mouse.

Power Supply rack

The Power Supply rack contains all the power sources for the System. The rack consists of the system power switch and a series of LEDs labelled with voltage values. The LEDs indicate the status of the given power source. On the actuator power panel, each of the labelled panels has a set of LEDs that indicate the status of the power to its respective subsystem of the System's controls. Each LED has a voltage label. When the system power switch is in the **ON** position, the LEDs indicate the status of the respective power supplies. When the LED is lit, the power source for the given value is **ON** and ready.

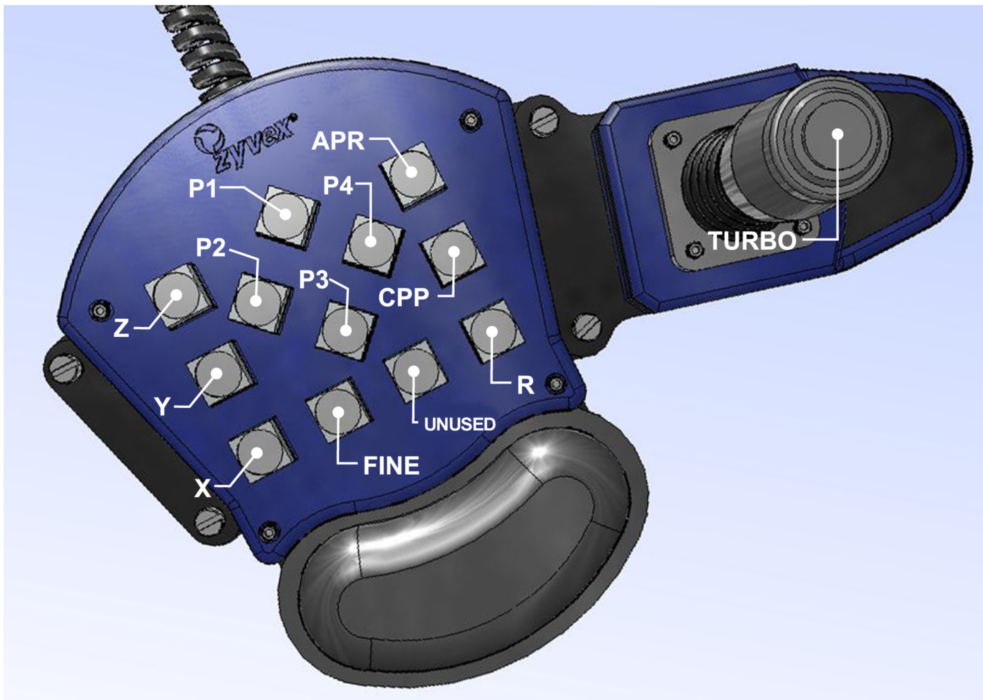


Controls

The System Controls consist of the keypad, joystick, and software.

Keypad and Joystick

The Keypad and Joystick are assembled in a single housing. The Joystick controls all the motion of the positioners.



On the keypad, there are twelve switch buttons that are assigned to specific task(s). These buttons have an embedded single-color indicator LEDs. These buttons are grouped based on their function. Buttons with similar functions have the same LED color.

— Blue-embedded LED buttons indicate positioners **P1**, **P2**, **P3**, **P4**, and **R**.

— White-embedded LED buttons indicate axes **X**, **Y**, and **Z.**

— Amber-embedded LED buttons are special function buttons ***CPP***(Positioner Reset) and ***APR*** (System Reset).

— Green-embedded LED buttons indicate fine positioning.

Pressing any one of these buttons toggles it **ON/OFF**. When the button is in the **ON** state, the LED of the button is illuminated. Pressing it again changes the state of the button to **OFF** and turns the button's LED off.

For a complete description of keypad controls, see Chapter 8: "Using the System Software, Keypad, and Joystick Controls" on page 43.

Once the motion setup is complete in the software, the user can control the nanomanipulator exclusively using the keypad and joystick.

Software

The Nanomanipulator System Software provides general system information to the user, such as

— Currently selected coordinate system

— Current selected positioner

— Real-time joystick information

In addition to the real-time information, the software provides an interface for setting

— Speed rates of all the positioners--both extended range and fine axes, if applicable.

— System level attributes such as communication with various devices in the system, max/min allowable amplifiers output, and polling cycle rate.

Note: Some system attributes are password protected and can only be accessed by Zyvex technicians.

For a detailed description of the different parts of the GUI, please see Chapter 8: “Using the System Software, Keypad, and Joystick Controls” on page 43.

Head and Positioners

The head assembly contains the positioners, base plate, and vacuum side connectors. Various NanoEffectors can be mounted to manipulate samples on an optional rotational sample stage.

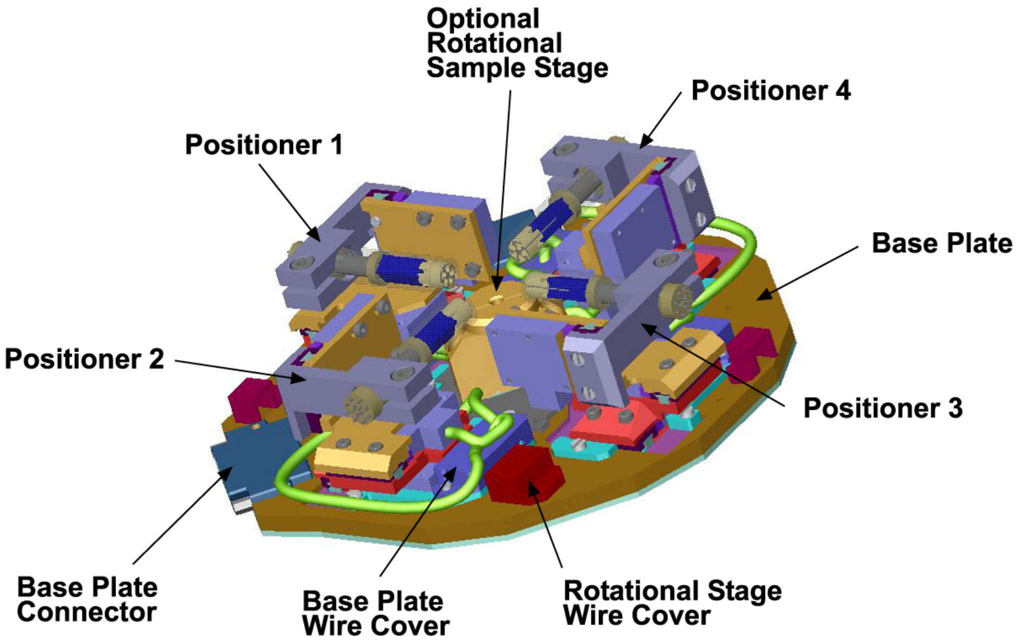


Figure 1: Front view of the header assembly

Positioner 1 is located between the two base plate connectors. Positioner 2, Positioner 3, and Positioners 4, respectively, follow counterclockwise from Positioner 1.

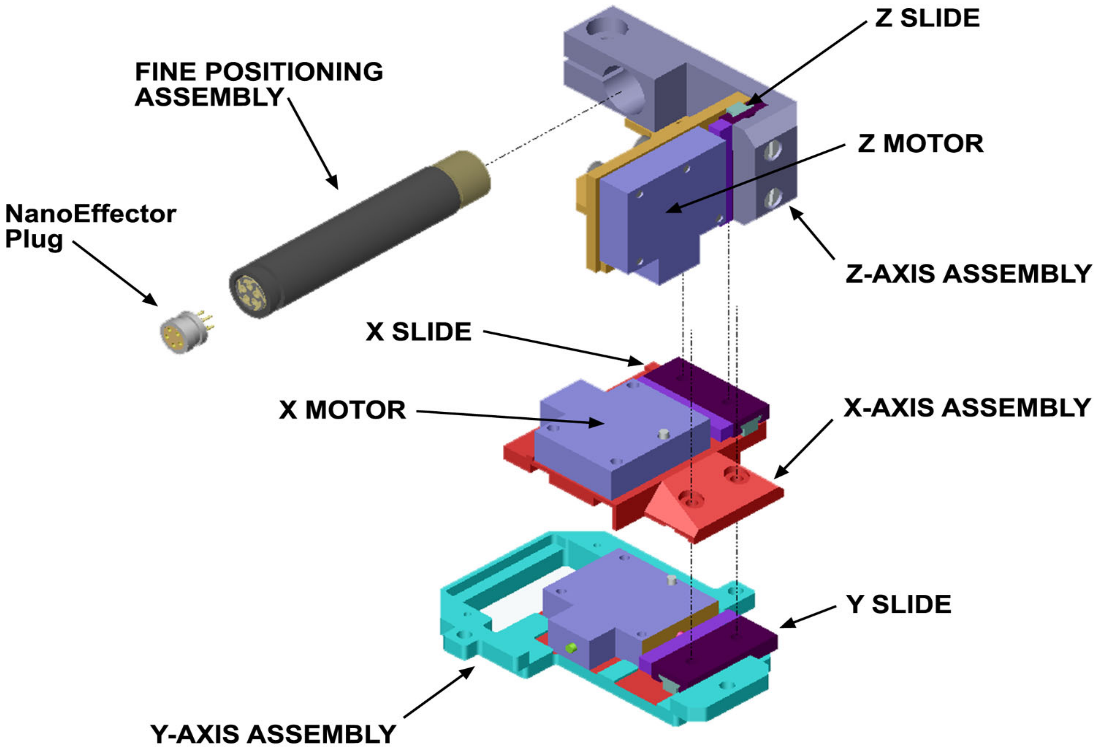


Figure 2: Exploded view of the nanomanipulator positioner

Adapter Ring

The Adapter Ring is located on the bottom of the base plate of the head assembly and used to mount the base plate to your equipment's adapter mount. For example, the nanomanipulator system for the SEM has an adapter ring (Figure 4) that fits into the adapter riser of a SEM equipment (Figure 5).

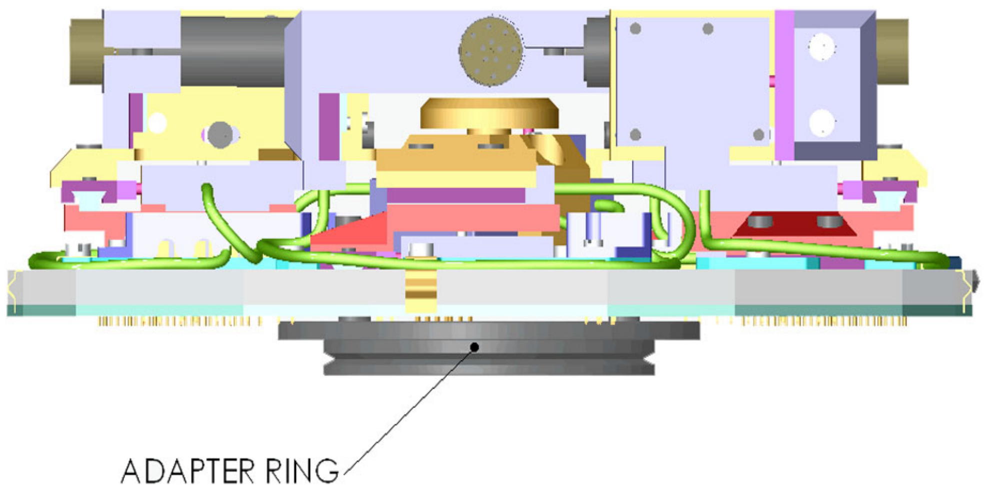


Figure 3: Adapter Ring

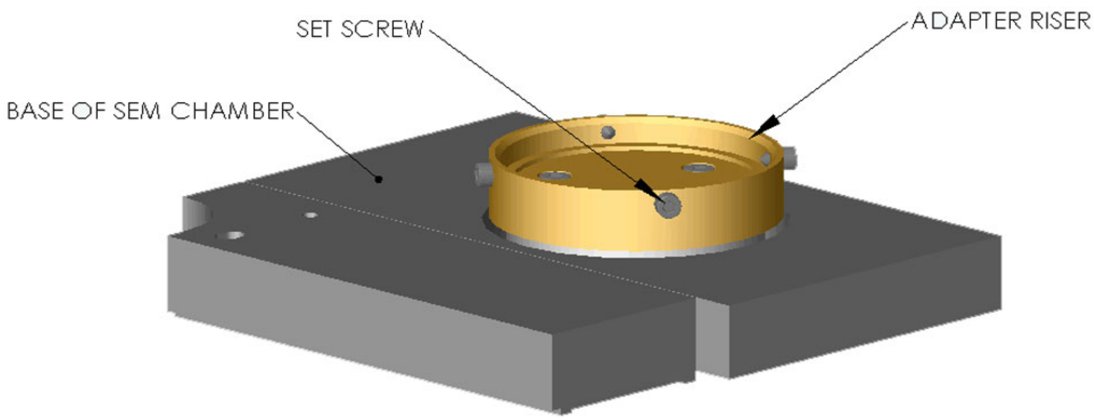


Figure 4: SEM Adapter Riser Example

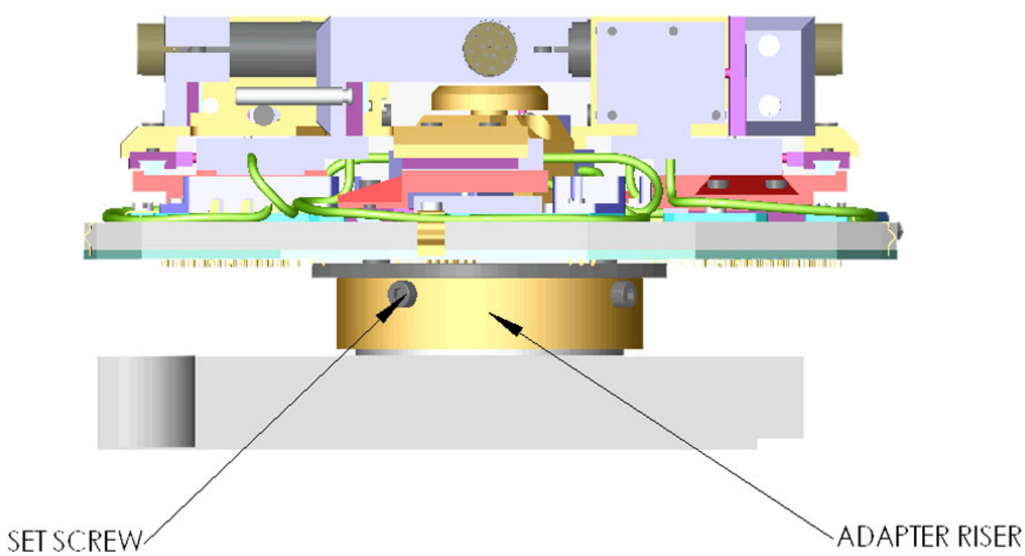


Figure 5: Adapter Ring Mounted onto the SEM Adapter Riser

Safety Interlock

The nanomanipulator's actuators require high driving voltages. During vacuum pumpdown and venting, the inside chamber of your UHV equipment goes through a corona region of pressure. *Severe damage to the actuators can occur* if the nanomanipulator's driving voltages to the actuators are on at this time. To prevent this damage, the system includes a safety interlock. This subsystem is an additional level of safety. Users should still turn off the actuators during pumpdown and venting.

The safety interlock consists of a thermocouple vacuum gauge and a controller. The thermocouple gauge controller continuously monitors the vacuum level through readout from the vacuum gauge (based on thermal conductivity of air or nitrogen) inside the UHV equipment when the nanomanipulator system is in operation. The data is then fed into the control system.

The data from the thermocouple gauge controller is compared with preset upper and lower vacuum limits. If the data falls between these two values, the control system automatically resets all the high driving voltages to the system actuators and inhibits actuations. The values of the upper and lower vacuum limits can only be set by Zyvex employees during installation.

The actuators become operational again when the data from the thermocouple gauge controller to the control system is outside the preset upper and lower vacuum limits.

Feedthrough

The feedthrough is the conduit that connects the driving signals from the system cabinet electronics to the head assembly. It provides connections from the NanoEffectors from all the positioners to the Patch Panel cards on the Patch Panel rack. And it allows vacuum-side and air-side connections for the system.

Feedthrough connector

For UHV applications, there are 2 feedthrough cables: the in-vacuum cable and the outside-vacuum cable. The in-vacuum cable connects the feedthrough to the head assembly. The outside-vacuum cable connects the cabinet to the feedthrough.

Green wire

The green wire is located on the outside feedthrough connector. It is connected to the ground of the nanomanipulator base plate and can be used as a clean ground for high sensitivity measurements.

System and Equipment Specifications

Cabinet Footprint

(W x D x H)
59.37 cm x 64.77 cm x 110.17 cm
23.37" x 25.5" x 43.37"

Nanomanipulator Head Assembly Footprint

(L x W x H)
14.48 cm x 14.48 cm x 4.15 cm
5.7" x 5.7" x 1.62"

Cabinet Power Supply

100-240 V / 50-60 Hz (to be specified when ordering your Nanomanipulator System)

Vacuum Compatibility

Down to 10^{-6} Torr (for applicable systems)

Maximum Range of Motion

12 mm in X, Y, and Z axes
θ (rotational) = 360° (continuous)

Positioner Resolution

Extended range axes resolution: better than 100 nm.
Fine axes resolution: better than 5 nm.

Chapter 6: Storage and Cleaning

This chapter outlines the recommended storage and cleaning methods for the nanomanipulator head assemblies used in a UHV environment. However, the same storage and cleaning methods are suggested for ambient applications.

Storage

Store the head assembly and vacuum-side feedthrough cabling in a dry box. Any contamination on the head assembly and positioners will increase the time it takes for your UHV system to reach optimal vacuum conditions. Condensation and moisture also increase the time it takes to reach vacuum.

If condensation does occur or if the system is slightly contaminated, spray the affected areas with methanol or isopropyl, and then spray with dry air, compressed nitrogen, or other inert gas to promote evaporation. See the cleaning section below for more information on cleaning the nanomanipulator system.

If the system has been out of the vacuum chamber for a period of time and your equipment has a purging system, place it in the chamber and upon closing the chamber door, purge the system for a few minutes with nitrogen or another inert gas. Purging the system also helps to lessen the effects caused by slight humidity in the atmosphere, which may stick to the nanomanipulator system, hence lengthening the time it takes to pumpdown to the chamber's optimal vacuum condition. Consult your equipment's user manual for further information on purging and to learn if your UHV system has this capability.

Cleaning

When necessary, clean the external surfaces of the nanomanipulator system with methanol or isopropyl and air blow with dry air or compressed nitrogen. Always handle the system with clean, powder-free, SEM or FIB compatible gloves. Wipe the system with a lint-free cloth or scientific cotton swabs.

If the head is contaminated to the extent that cleaning the external surfaces is not sufficient, please contact Zyvex for further instructions.

Chapter 7: Installation and Setup

This chapter explains how to complete the following procedures:

- Connecting the Keypad and Joystick
- Connecting NanoEffectors to positioners
- Mounting the nanomanipulator head assembly into your equipment
- Powering-on the Nanomanipulator System
- Removing the nanomanipulator head assembly from your equipment

System Installation

The Nanomanipulator System purchase includes on-site installation. Each head assembly comes with a custom-designed adapter mount for your equipment model. Installation into other equipment or equipment models requires purchasing additional adapters and vacuum feedthroughs.

Safety Precautions

Follow these Safety Precautions when inserting and removing the nanomanipulator head assembly from your equipment:

- Ensure that the system power is off, and make sure to follow the proper procedures to prevent electrical shock.
- Wear clean, powder-free, SEM or dual-beam FIB compatible gloves to minimize system contamination for UHV applications.
- Use both hands when placing the nanomanipulator head assembly into the vacuum chamber (if applicable). Be careful when handling the head assembly to avoid damaging the positioner wiring.

Connecting the Keypad and Joystick

To connect the keypad and joystick to the PC on the Nanomanipulator System, connect both the RS232 and USB connectors on the keypad/joystick cable to the respective female connector at the back of the PC rack.

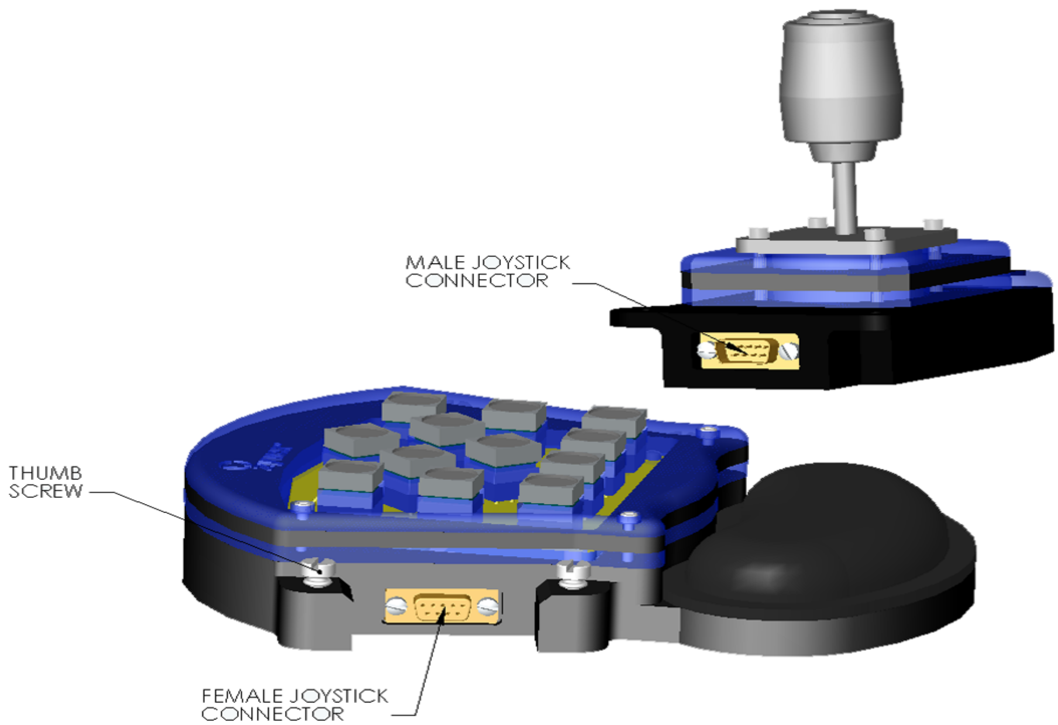
Note: The joystick is comfortable for both right- and left-handed users. You can connect the joystick to either the left or the right side of the keypad.

To connect the joystick to the keypad:

1 Loosen the thumbscrews to remove the keypad/joystick wire cover.

2 Insert the male joystick connector into either the left- or right-side female connector on the keypad.

3 Tighten the thumbscrews and replace the cover on the unused female keypad connector.

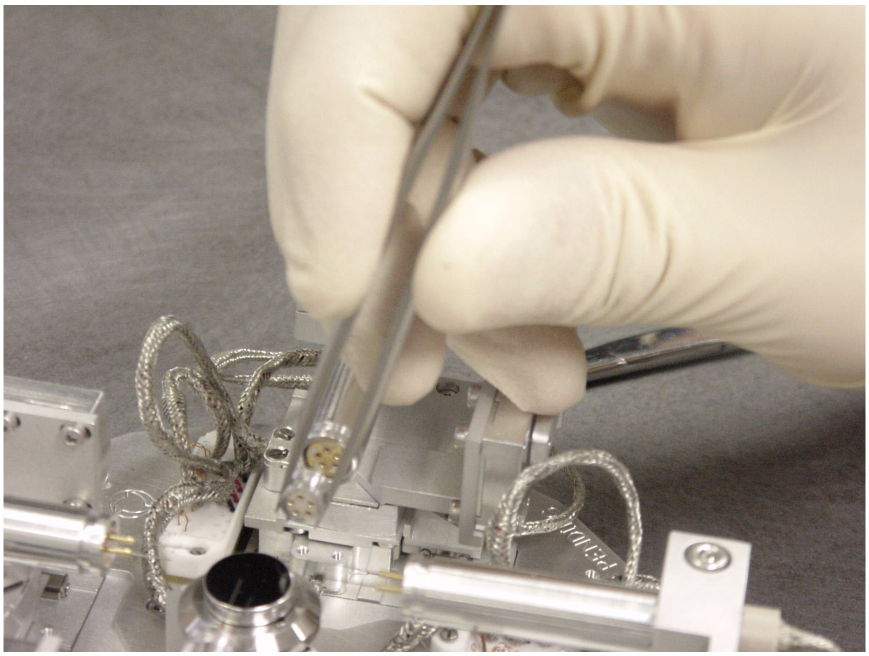


Connecting NanoEffector Plugs to Positioners

To connect a NanoEffector plug to a positioner:

1 Use the tweezers provided to align the NanoEffector plug pins to the connectors.

2 Insert the NanoEffector plug straight into the fine positioner assembly.



CAUTION: Inserting the NanoEffector using sideways motion can break the fine positioning assembly.

Mounting the nanomanipulator into your equipment

The nanomanipulator head assembly is designed to fit securely into your equipment. Zyvex custom fits an adapter mount for your equipment. The nanomanipulator head assembly sits in an adapter riser on this adapter mount.

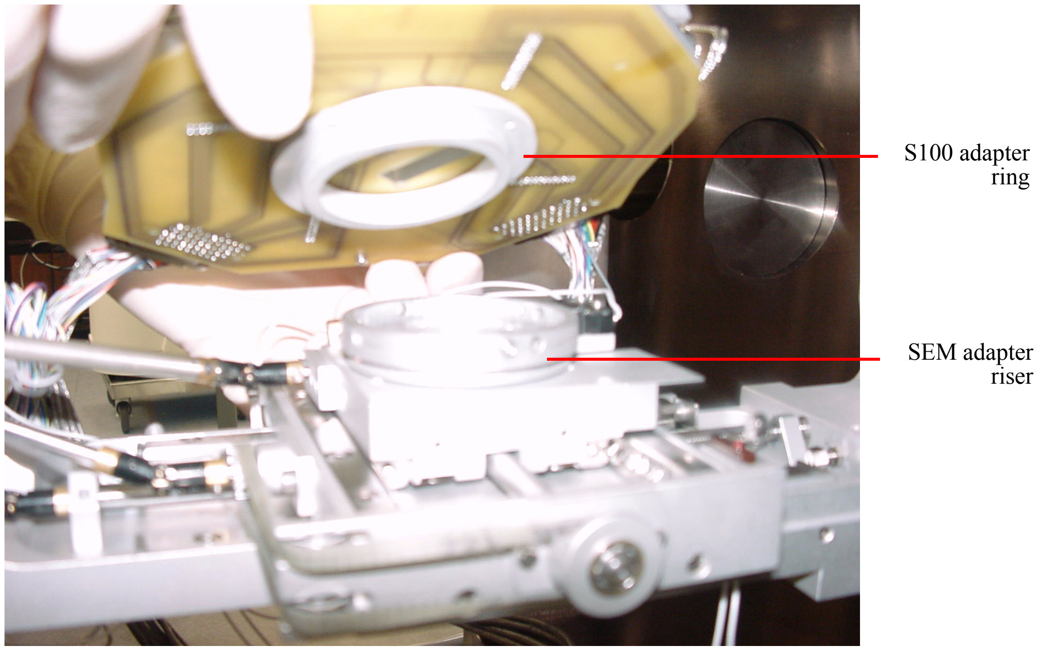
To mount the head assembly into the SEM,

1 Open the SEM chamber door.

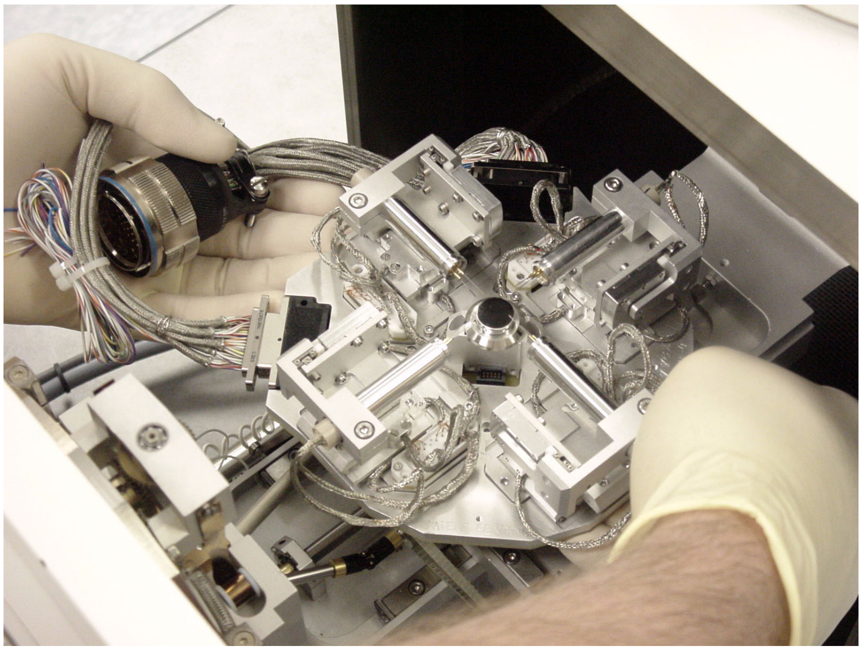
2 Ensure that the center stage is at its lowest position so that the nanomanipulator system will clear the SEM objective lens.

3 Retract the set screws on the adapter riser.

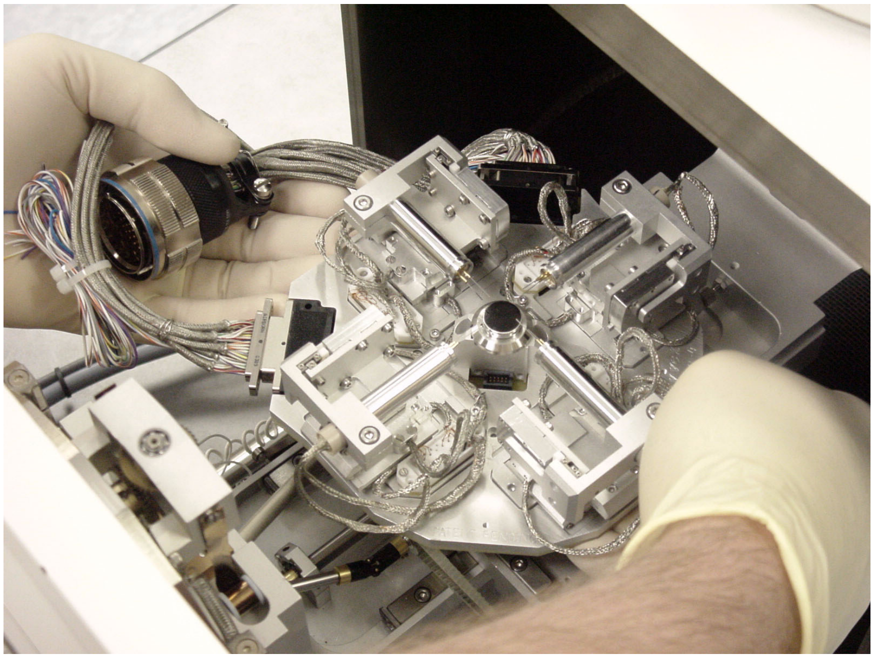
4 Align the adapter ring at the base of the head assembly into the adapter riser.



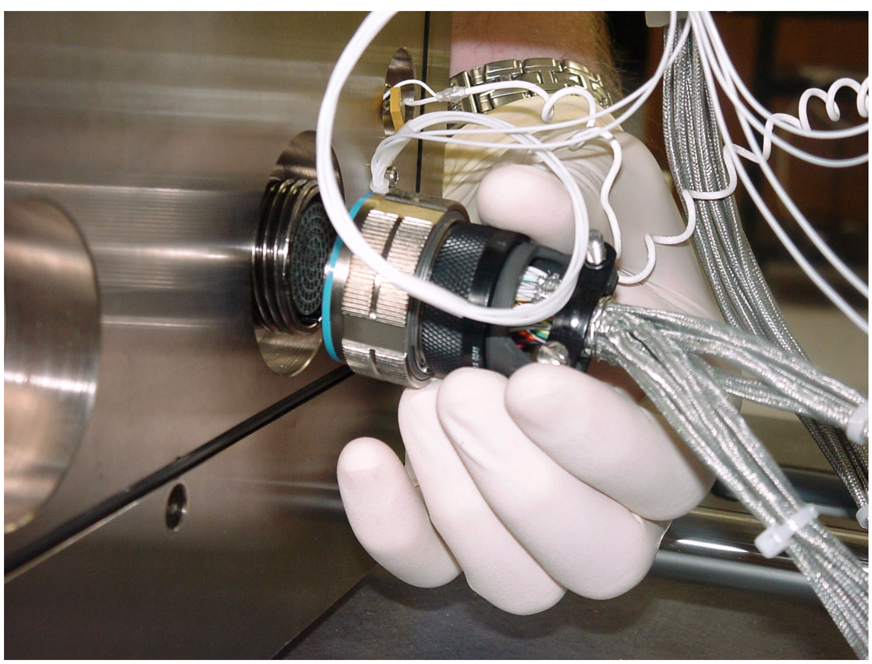
5 Use both hands to orient the head assembly so that the connectors face the feedthrough port. Orienting it this way minimizes tension on the wiring and makes it easier to attach the connector.



6 Finger tighten the screws on the adapter riser.



7 Connect the in-vacuum connector to the vacuum electrical feedthrough.



Note: This connector is keyed and will only connect to the vacuum side electrical feedthrough one way. As you turn the connector, it clicks and is fully connected after one full rotation (360 degrees).

8 To square the head assembly, use the stage controls to rotate the center stage.

CAUTION: Do not rotate the head assembly more than 1/4 of a turn. Doing so may damage one of the connectors by causing too much tension in the wiring.

9 Ensure that the assembly will clear the SEM objective lens and that the wiring will clear the door before you close the SEM chamber door.

10 Pumpdown the system.

Note: The system actuators require high driving voltages. During SEM pumpdown and venting, the inside chamber of the SEM goes through a corona region of pressure. If the system's driving voltages to the actuators are on at this time, severe damage to the actuators can occur. To prevent this damage, the Nanomanipulator System includes a Safety Interlock to continuously monitor the vacuum level and report the data to the control system, which automatically resets all the high driving voltages to the system actuators and inhibits actuations. For a detailed description of the Safety Interlock, see Chapter 5, "Safety Interlock" on page 25.

11 Connect the external wiring harness to the air side of the vacuum electrical feedthrough.

Note: Before you start imaging, you may want to adjust the Z height of the system to within the optimal working distance of your SEM.

To mount the head assembly into the dual-beam FIB (similar instructions to mounting into a SEM):

1 Open the dual-beam FIB chamber door.

2 Ensure that the FIB stage is at its lowest point so that the head assembly will clear the SEM column and focused-ion beam.

3 Loosen the screws on the adapter riser attached to the dual-beam FIB stage.

Note: The Y-lever for the dual-beam FIB and the custom adapter mount should already be installed.

4 Align the adapter ring at the base of the head assembly to the adapter riser.

5 Use both hands to orient the head assembly so that the connectors face the feedthrough port. Orienting it this way minimizes tension on the wiring and makes it easier to attach the connector.

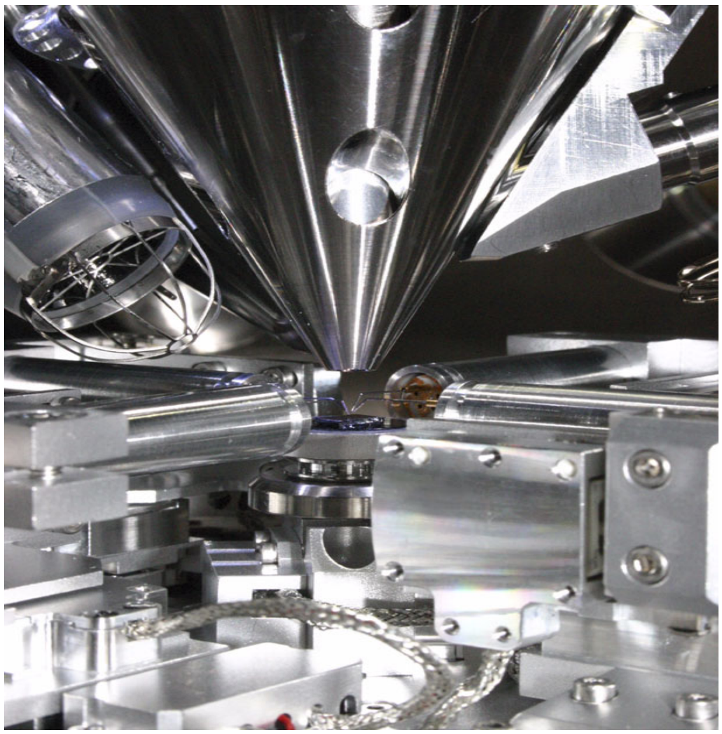
6 Finger tighten the screws on the adapter riser.

7 Connect the in-vacuum connector to the vacuum electrical feedthrough.

Note: This connector is keyed and will only connect to the vacuum side electrical feedthrough one way. As you turn the connector, it clicks and is fully connected after one full rotation (360 degrees).

8 To square the system, use the dual-beam FIB stage controls.

9 Ensure that the head assembly will clear the SEM column and focused-ion beam and that the wiring will clear the door before you close the chamber. The dual-beam FIB has touch alarms if anything touches the chamber wall. Be sure that the wiring does not touch the chamber wall.



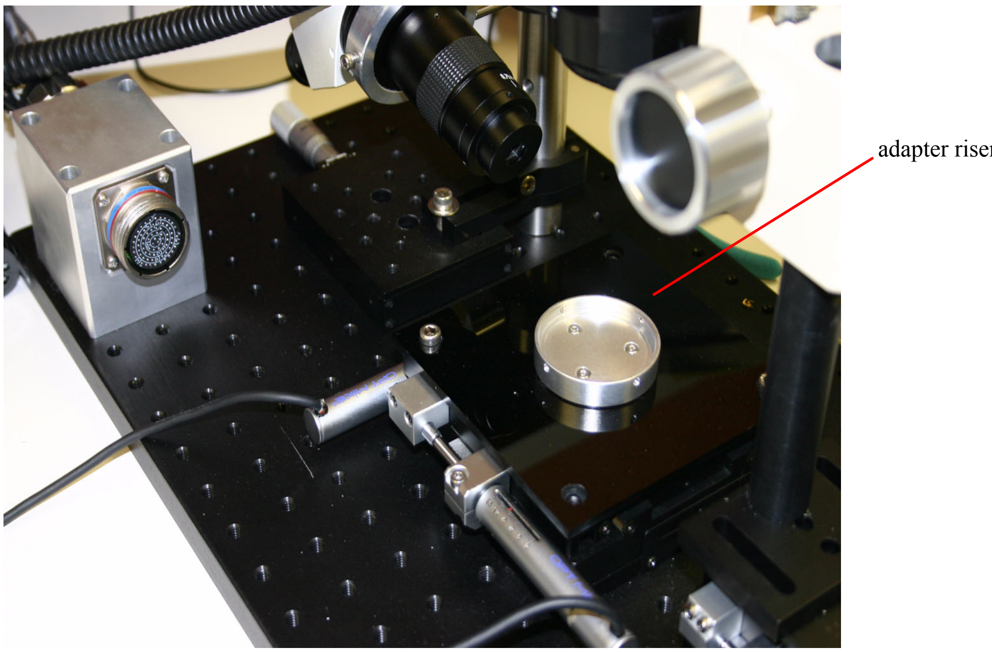
10 Pumpdown the system.

Note: The system actuators require high driving voltages. During pumpdown and venting, the inside chamber goes through a corona region of pressure. If the driving voltages to the actuators are on at this time, severe damage to the actuators can occur. To prevent this damage, the Nanomanipulator System includes a Safety Interlock to continuously monitor the vacuum level and report the data to the control system, which automatically resets all the high driving voltages to the system actuators and inhibits actuations. For a detailed description of the Safety Interlock, see Chapter 5, ”Safety Interlock” on page 25.

11 Connect the external wiring harness to the air side of the vacuum electrical feedthrough.

To mount the head assembly into an optical or electron microscope:

1 If applicable, ensure that the center stage is at its lowest position so the system will clear the microscope's objective lens.



2 Loosen the set screws on the adapater riser on your microscope.

3 Align the adapter ring at the base of the head assembly into the adapter riser. Use both hands to orient the system.

4 Finger tighten the set screws on your adapter riser.

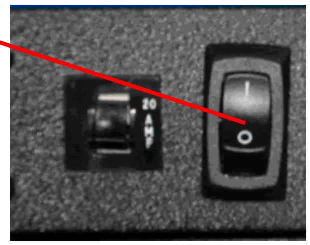
Powering-on the Nanomanipulator System

Powering-on the Nanomanipulator System is a two-step process that involves turning on the basic control system and turning on the actuators and driving electronics. To power-on the Nanomanipulator System, complete the following steps.

To turn on the basic control system:

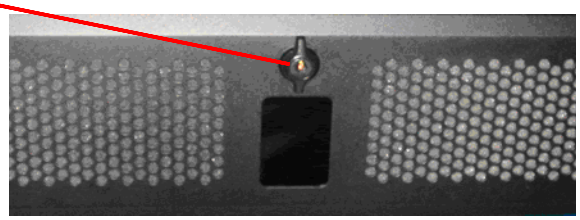
1 Turn on the System Master Switch located at the top left portion of the cabinet.

System Master Switch



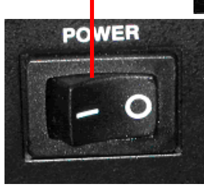
2 Rotate the PC Rack lock clockwise (1/4 turn), and open the door of the rack to expose the PC components and Switch.

PC Rack lock



3 Press the PC Switch once.

PC Switch



4 The PC Power LED should now be lit.

5 Make sure the LCD monitor is on, and wait for the system to boot up and display the Windows login.

6 Log in to the system.

Note: Zyvex does not set a login password before shipping the system. Users should set the user-id and password for the system to prevent unauthorized use of the system.

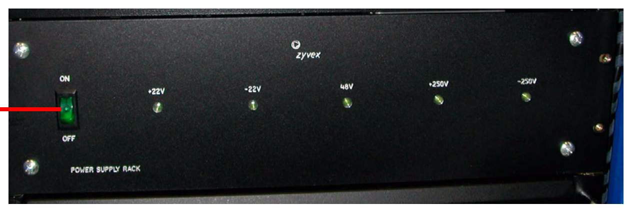
7 Open the application (usually found in the Start Menu under the Programs folder and then under the Zyvex folder).

Once you have completed these steps, you are ready to use the Nanomanipulator System Software. For further instructions, see Chapter 8, "Using the System Software, Keypad, and Joystick Controls" on page 43.

To turn on the Nanomanipulator System actuators and driving electronics:

1 Locate the Power Supply Rack directly below the Drawer.

Power Supply Switch



2 Turn on the Power Supply Switch.

Removing the nanomanipulator from your equipment

To remove the head assembly from your equipment:

1 Push System Reset on the keypad.

2 Using extended range motion, back away the 4 positioners in Y (local coordinates), and run Z positioners down midway to ensure that the NanoEffectors clear the sample stage.

3 Turn off the Power Supply Switch.

4 For UHV applications, vent the equipment and open the chamber door.

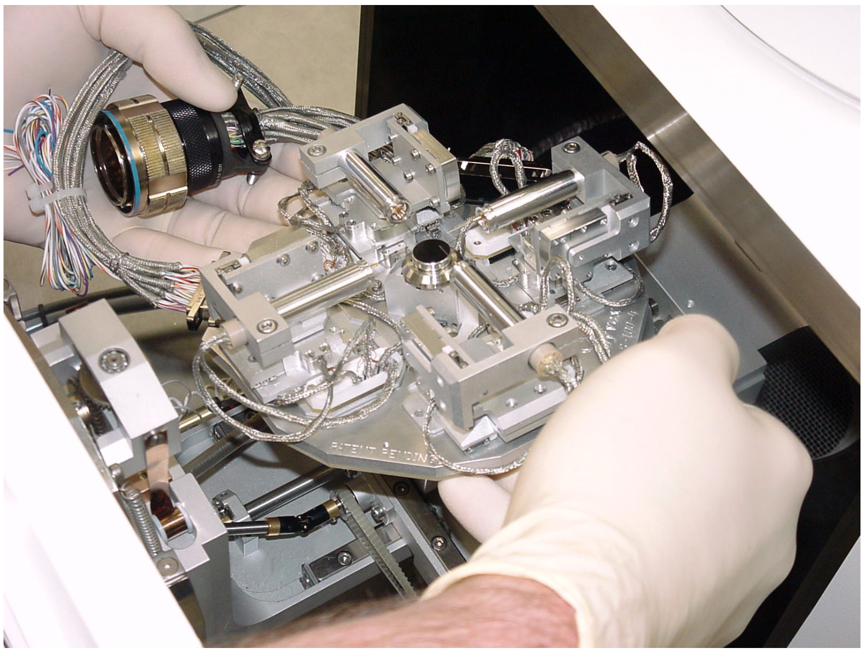
5 Run the stage down in the Z axis enough to clear the objective lens.

6 Turn off the software and System Power Switch.

7 Disconnect the feedthrough and cable.

8 Loosen the screws on the adapter riser.

9 Remove the base plate with both hands while holding the vacuum side connector to minimize tension to the wiring.



Chapter 8: Using the System Software, Keypad, and Joystick Controls

This chapter explains how to use the System Software, keypad, and joystick controls.

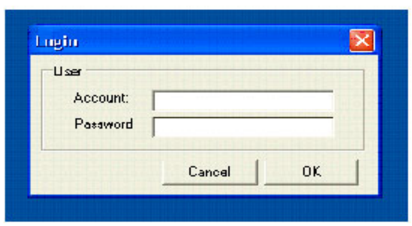
Launching the System Software

After you insert the head assembly and power-on the Nanomanipulator System, as instructed in Chapter 7, you can launch the System software.

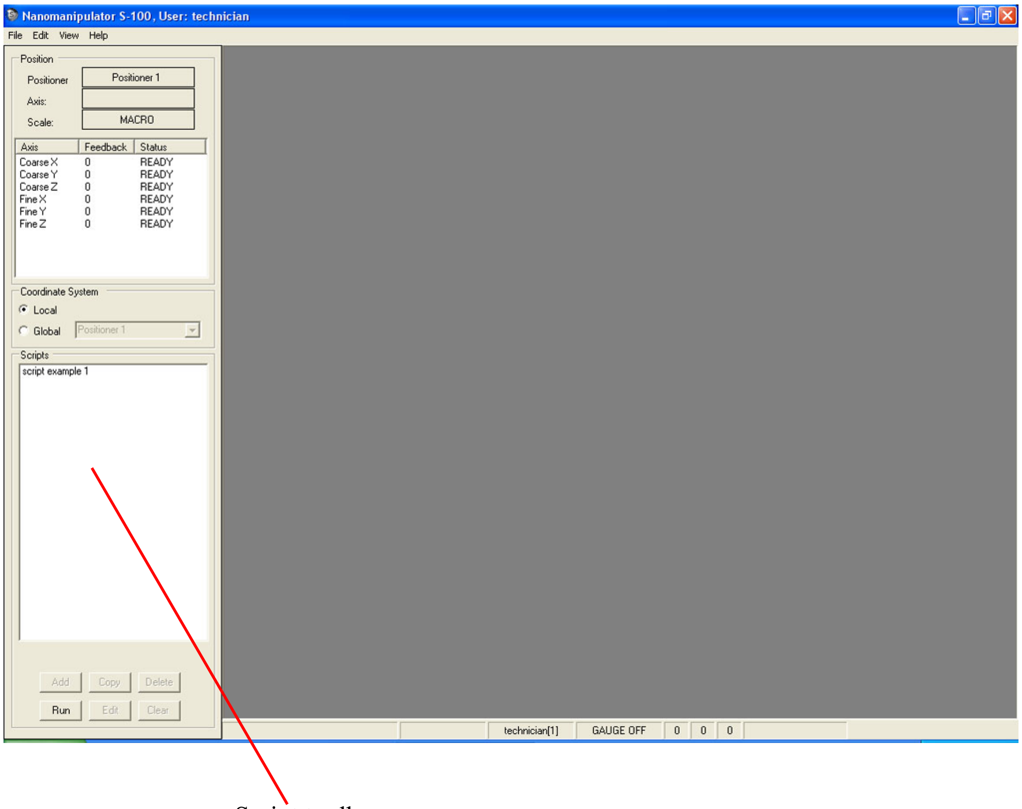
To launch the software:

1 Open the application (usually found in the Start Menu under the Programs folder and then under the Zyvex folder).

The Login box appears. Please login with your user name and password.



2 Once the system acknowledges your account, you should see the user interface window.



Script toolbox

Getting Help

To access help on using the software, you can either any of the following:

- Go to the Menu item "Help" and select "Topics."
- Press F1 on your keyboard.

For questions that were not answered in the help documentation, please contact Zyvex Support at tools.support@zyvex.com.

Using the System Main Menu

Access Levels

The software for the Nanomanipulator System recognizes three basic levels of access:

- Operator Access: Access Level 0

• This is the lowest level of access. It is restricted to general setup and operation functions.

- Technician Access: Access Level 1
  • In addition to all operator access functions, this level can change many of the operating parameters and can run scripts.
- Engineer Access: Access Level 2
  • In addition to all operator and technician access functions, this level can create user accounts as well as create and edit scripts.
- Super User Access: Access Level 2
  • In addition to all operator and technician access functions, this level can create user accounts as well as create and edit scripts.

When the system is initially installed, there are 4 default access accounts established in the software. They are as follows:

Account Name	Account Password	Access Level
operator	oper	0
technician	tech	1
engineer	engi	2
super	user	2

It is highly recommended that your administrator changes the passwords and user accounts after software installation.

System Main Menu

The main menu has five sub-menus: File, Edit, View, Commands, and Help. The options available under each sub-menu depends on the user's access level. A list of the commands under each sub-menu is provided below.

File Menu:

Option Name	Description
Configuration -> Edit Machine	View/Edit system wide parameters
Configuration -> Edit User	View parameters associated with current user
Configuration -> Restore Defauts	Change all user parameters to the default (super user)
Exit	Closes the application

Edit Menu:

Option Name	Description
Access Level	Changes the current access level.
Access Accounts	Manages the list of users allowed to use the system.
Joystick Button Map	Changes mapping of joystick buttons to scripts or menu options.
Positioner Properties	Modifies positioner's specific properties.

View Menu:

Option Name	Description
Joystick	Changes the joystick being used by the application. The software recognizes three options: * Zyvex Joystick (default) * Virtual Joystick * Generic Joystick (any Direct X joystick)
IO Table	Displays the digital IO table.
Console	Displays a console window showing information/messages about the system execution.
Remote Interface	Allows viewing of remote interface status windows.
Positioner Diagnostics	Displays advanced positioner diagnostic information.

Help Menu:

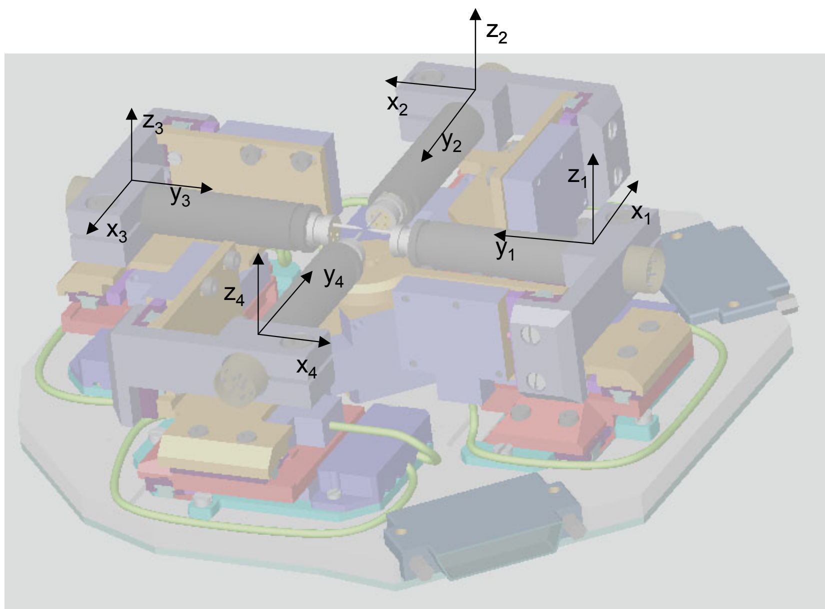
Option Name	Description
About	Displays software version information.
Topics	Displays the application help file.

System Terminology

Coordinate System

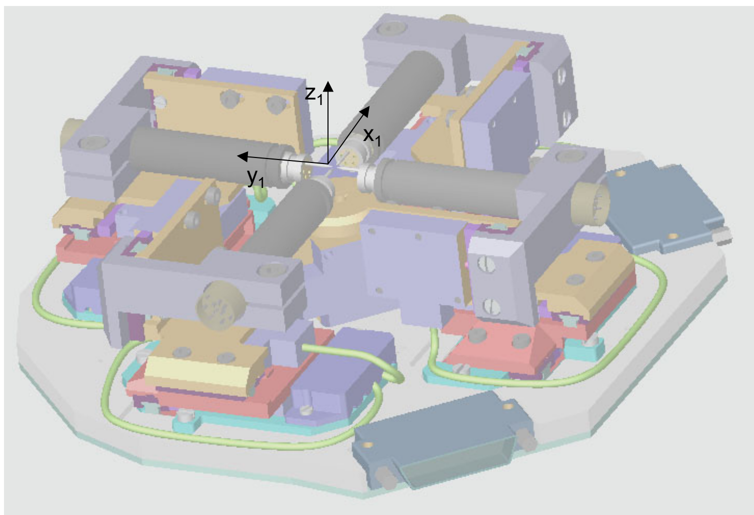
Local Coordinate System

In the Local Coordinate System, each positioner has its own X, Y, and Z coordinates, which are defined relative to the sample stage. The axis direction facing the stage area is defined as the Y-axis' positive direction. Angular motion of the positioner head rotates about the Y-axis, and a positive rotation is defined as a point travelling from the positive Z-Axis to the positive X-Axis (i.e., following the Right Hand Rule for magnetic force).



Global Coordinate System

In the Global Coordinate System, there is one reference origin for all the axes. Users can select this reference from among the various positioners' axis systems, as shown below. The axes' labels and directions are all fixed. This system can help eliminate any confusion concerning axes directions of the different positioners.

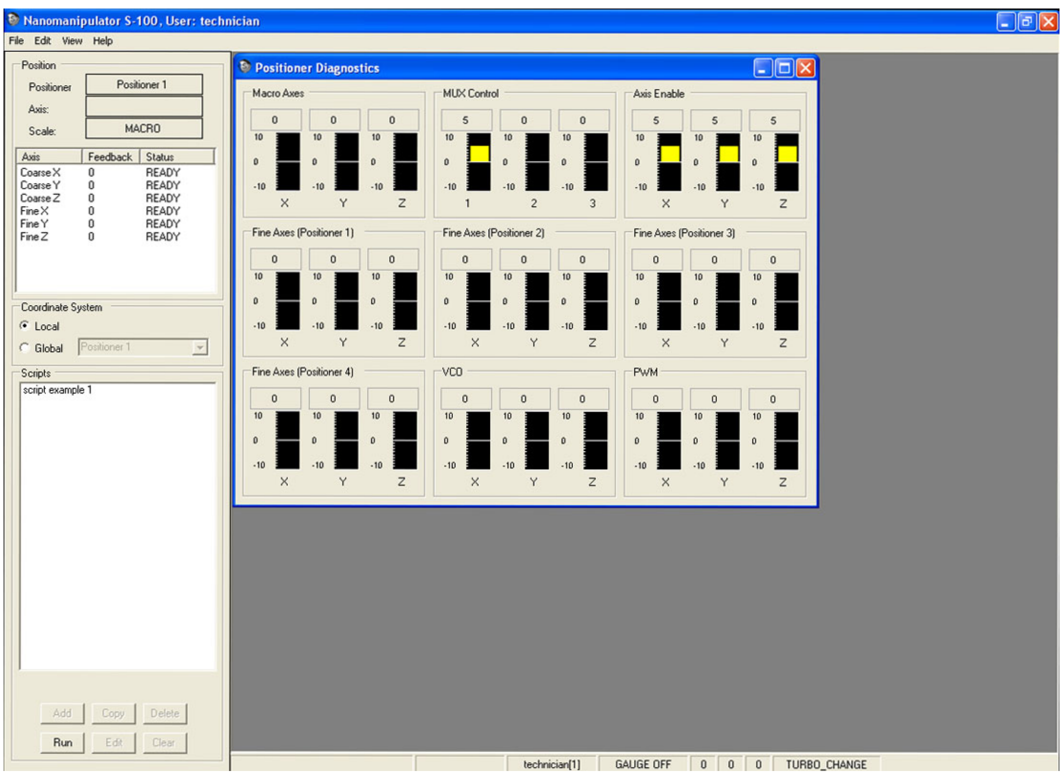


Users can choose the Local or Global Coordinate System based on their preference.

System Control

Positioner Diagnostics

This window displays the current selections of extended range adjustment or fine adjustment (CA/FA) positioners and speed mode. This window displays output voltage being applied to the DAC boards, as reflected in the Extended Range Axes and Fine Axes Outputs in the right portion of the menu. The real-time joystick information for the X, Y, and Z axes is displayed at the bottom of the user interface window.



Fine Axis Positioner Reset (for applicable systems)

Reset All Positioners

The Reset All Positioners script allows you to reset the voltages to their default values.

Current Positioner Reset

The Current Positioner Reset script allows you to reset the state of the current positioner. When you run this script, the following actions occur:

•Any current motion on that positioner is halted.

•All motor output ceases.

•For every fine axis that is selected, the fine axis will be moved to its reset position.

Note: You need to have an access level of 2 in order to edit these set of scripts.

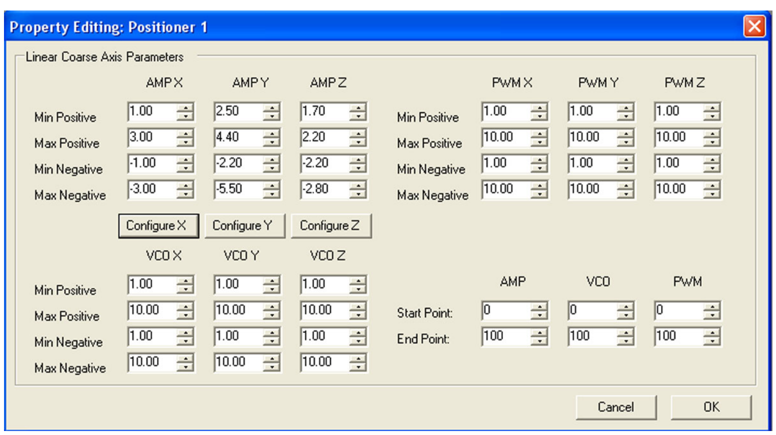
Setup Access

Although you may prefer to use the default settings initialized upon Zyvex installation of the system, you can adjust the settings as needed. Settings for different operations are stored under the current user's profile, which can allow multiple users to customize their settings. The current user can customize settings for his/her account. Any changes made will not be configured on any other accounts.

Positioner Properties

You can configure the DAC mapping between 1-100% velocity commands in the positive and negative directions for each axis.

For example in the "Property Edition: Positioner 3" window below, a 1% Velocity in the X positive direction will output 1.3V to the motor. Between 1 and 100% velocity commands, the voltage will be evenly scaled between 1.3 and 3.2 in the X positive direction.

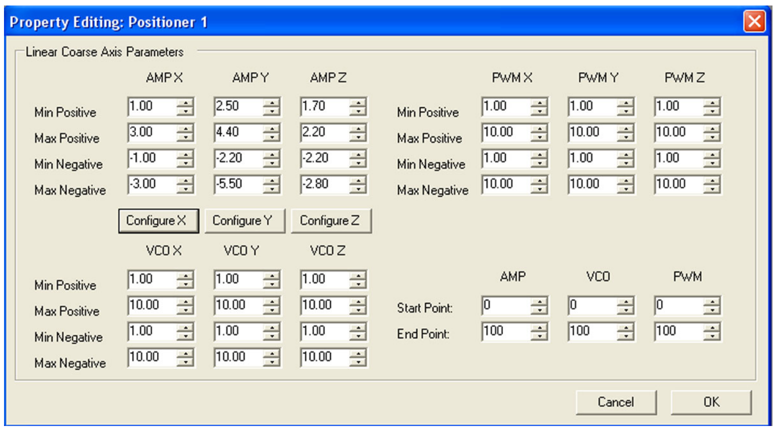


You can interactively teach these numbers to the software for a given axis.

To configure the DAC mapping for a given axis:

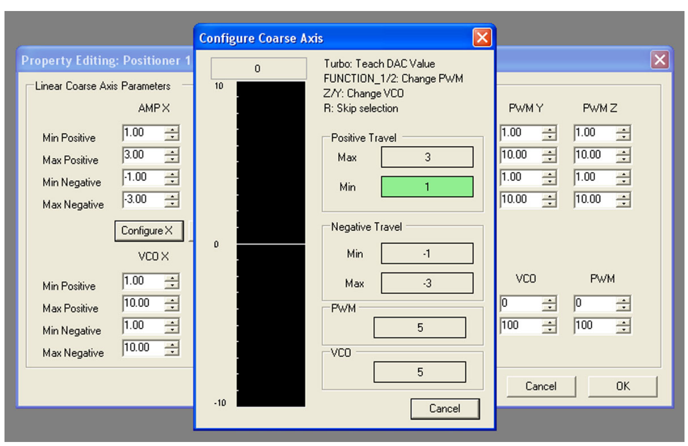
1 Go to the Edit Menu.

2 Select “Positioner Properties” and pick the positioner you wish to configure. The following pop-up window, “Property editing” should appear on your workspace for the positioner you chose.



3 Select the axis you wish to configure.

4 Another pop-up window, “Configure Coarse Axis” should appear on your workspace.



5 Deflect the joystick in the direction of the axis you are teaching to change the DAC value. (The parameter being taught will be selected in green.)

6 Press the “Turbo” button on the joystick to configure the parameter. When the “Turbo” button is pressed, the current DAC value will be recorded in the highlighted field, and the next field will be automatically selected (in green).

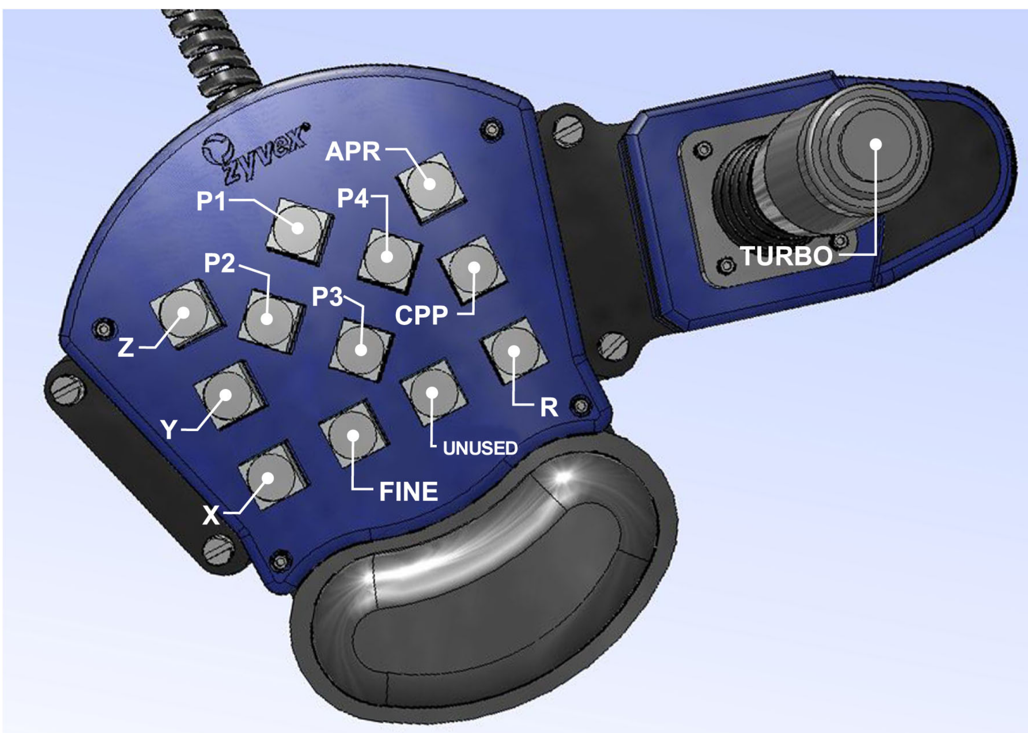
7 Repeat steps 5 and 6 for each of the four travel parameters--Max Positive Travel, Min Positive Travel, Min Negative Travel, and Max Negative Travel. Once all four parameters have been taught, the values are saved, and the window automatically closes.

Configuration Edit

Under the File Menu, “Edit Configuration” allows you to edit the current user’s configuration file. Some of the parameters associated with the operation of the system can be modified through the configuration editor. Making edits to the configuration items should be done with great care because it can affect the way your system performs.

Note: You need to have an access level of 2 in order to edit the configuration file.

Keypad Controls



X Indicator/button

The X button controls the selection of the X-axis of motion for the selected positioner. When the indicator LED is in the on (lit) state, the X-axis is selected. When the user moves the joystick in this direction, actuation results.

Y Indicator/button

The Y button controls the selection of the Y-axis of motion for the selected positioner. When the indicator LED is in the on (lit) state, the Y-axis is selected. When the user moves the joystick in this direction, actuation results.

Z Indicator/button

The Z button controls the selection of the Z-axis of motion for the selected positioner. When the indicator LED is in the on (lit) state, the Z-axis is selected. When the user twists the joystick in the counter-clockwise rotation, actuation results in the (+) positive Z-axis direction. A clockwise twist results in the motion being in the (-) negative direction.

Rotation Indicator/button

For nanomanipulator systems equipped with positioners with three degrees of freedom and a rotational sample stage, the Rotation button (R) selects the rotational axis of motion and results in joystick actuation of the sample stage's rotational movement. When the indicator LED is in the on (lit) state, the rotational axis is selected. When rotational motion is selected, all the other axes are disabled. Pressing one of the four positioner keys will cause the system to return to the state of selections of axes and extended range/fine motion—the state that it was in the last time the given positioner was selected.

For nanomanipulator systems equipped with positioners with four degrees of freedom and a rotational sample stage, the Rotation button (R) is used in conjunction with the Positioner Selection buttons (P1, P2, P3, and P4) to control the rotational axis of motion of the postioners and/or stage. In this case, the stage sits in one of the positioner slots and can be manipulated like a positioner.

Positioner Selection indicator/button

The P1, P2, P3, and P4 buttons control the selection of positioner 1, 2, 3, and 4 respectively. When the indicator LED is in the on (lit) state, the associated positioner is selected. When the user moves the joystick in this positioner, actuation results. Only one positioner may be selected at a time, thus selection of a positioner automatically cancels selection of the other positioners.

FINE button (Extended Range/Fine Axis)

The FINE button toggles between using the extended range positioners and the fine positioners for motion for the currently selected positioner. When the system is turned on, it is initialized for extended range axis motion of the selected positioner, as indicated by the on (lit) state of the CA/FA LED. Pressing this button causes the system to enter a fine motion state and turns on the fine LED.

Voltage Reset buttons (for applicable systems)

The APR (All PZT Reset) button controls the PZT reset for the fine axis high voltage. Pressing this button sets the voltage to the default values on all piezos. The CPP (Current Positioner Preset) button resets the state of the current positioner.

Joystick Controls

Use the following joystick motion to achieve the desired positioner movement:

- Right and left motion is for positive and negative X motion respectively.
- Up and down motion is for positive and negative Y motion respectively.
- For nanomanipulator systems with positioners equipped with three degrees of freedom (X, Y and Z), counter-clockwise and clockwise motions are for positive and negative Z motion respectively.
- For nanomanipulator systems with positioners equipped with four degrees of freedom (X, Y, Z, and Θ), counter-clockwise and clockwise motions can be both for positive and negative Z motion as well as for positive and negative angular motion,respectively depending upon whether the user selects either the Z Indicator/button or the Rotation Indicator/button respectively on the keypad control).

Chapter 9: Applications and Examples

This chapter describes exercises and applications that demonstrate the functionality of the Nanomanipulator System. These experimental procedures use the basic functions of the nanomanipulator. Each exercise begins with a list of materials and is then followed by a procedure. Zyvex routinely releases application notes describing new and revolutionary applications for the nanomanipulator system. For more details, please contact the Zyvex sales team for the latest application notes.

Attaching a Multi-walled Nanotube to a NanoEffector Probe

This exercise demonstrates attaching a Multi-walled Nanotube (MWNT) to a probe, and it can help users become familiar with the user interface, ranges of motion, and responsiveness of the system inside a SEM.

Materials List

- MWNT: You should use a sample where nanotubes are protruding from the surface.
- Probes: Depending on the desired experiment, you can use AFM cantilevered probes or sharpened metal wires (such as Zyvex NanoEffector probes). These probes are included in the Probe Starter Kit.
- Carbon Tape: Use double-sided conductive tape, available from SEM supply distributors.
- SEM Mounts: These are available from SEM supply distributors for mounting samples at various angles.

Procedure

Carefully setting up the experiment prior to pumpdown will save time and help you to effectively complete the experiment.

To set up the experiment, complete the following steps as appropriate:

1. If you have a surface with aligned nanotubes, position the tubes onto the sample stage so that they are normal to the electron beam.
2. If the nanotubes are not aligned, then position them so that as many nanotubes as possible are normal to the electron beam and extend from the surface.
3. If the nanotubes are on a wire, you can mount them onto the sample stage or into one of the nanomanipulator positioners. Use the sample stage to minimize use of the positioners as sample place holders.
4. When mounting the probes, use the sharp probes.

CAUTION: To minimize damage to the probe tips, prepare the sample in advance. Although retracting the probes increases the maneuvering area, be careful when handling sharp probes. The sharp probes are extremely delicate. The sharp end of a probe cannot survive any manual physical contact.

5 Once you set up the nanomanipulator system and load the positioners, you can place it into the SEM for pumpdown.

6 Determine which positioners you will use first, and adjust the sample stage to appropriately position the nanotubes. You can best accomplish this by finding a target nanotube.

7 Record the value of the working distance once the nanotube is in focus. This will help align the probe tip to the nanotube later.

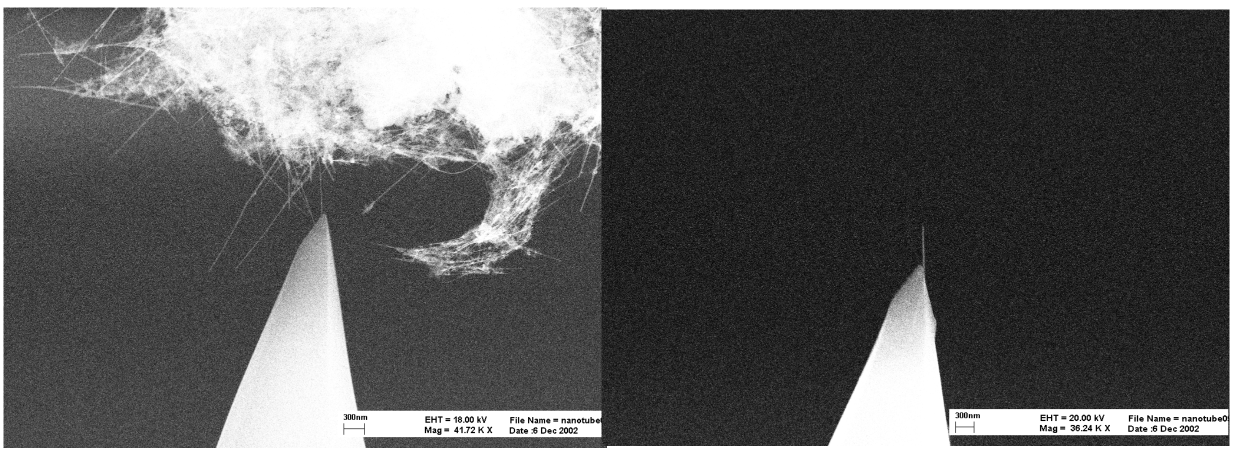


Figure 1: Probe approaching and attaching to a nanotube

Use the positioners to approach the nanotube and complete the following steps:

1 Adjust the X- and Y-axes to position the probe within the100 µm x 10 µm (X, Y respectively) working area of the fine positioner.

2 Align the Z-axis. Focus on the nanotube, and adjust the Z-axis extended range positioner until the probe is at the same working distance as the nanotube.

Note: Because changes in the Z-direction are the most difficult to monitor, you should not adjust the Z-axis any closer than 8 microns from the nanotube. This can damage or destroy your sample area or the probe in your Z-direction approach.

Switch to the fine positioners and complete the following steps:

1 Continue approaching the nanotube with the fine positioner. The Y-axis fine position can move up to 10 microns. If more motion is required, back away with the fine positioner and approach very slowly with the extended range motors.

Note: Avoid crashing the probe while approaching the target. If approaching a surface that is normal to the Z-axis, start by moving the probe in the positive Z-direction with the fine positioner until it is near its maximum. Switch to the extended range positioner and begin approaching the target. Keep checking to make sure the probe is within the range of the fine positioners, switching between extended range and fine modes. Once within range, perform the remainder of the experiment with the fine positioner.

2 When the probe is directly below the nanotube in the Z-axis, use the fine positioner in the Z-axis to contact the nanotube.

3 Confirm contact by observing either a change in screen brightness or physical displacement of the nanotube.

4 To attach the nanotube onto the probe, use Electron Beam Induced Deposition (EBID). See the Note below.

5 Wait an appropriate amount of time (seconds to a few minutes), and slowly back away the probe with the fine positioner.

As you back away the probe, the nanotube will remain attached, if there is enough EBID. EBID is a very stable way to attach a nanotube to a probe; however, the EBID technique can work a limited number of times, and it is often impossible to reweld an item.

Note: Electron Beam Induced Deposition (EBID) is a technique that you can employ using virtually any SEM. For a brief description of the EBID process, see Reference [1]. To summarize, the electron beam dissociates organic material (contamination, residue, etc.) from the chamber and deposits it onto the imaged surface. The material originates either from the migration of surface contamination on the sample itself or from residual gas. The deposition rate depends upon the imaging parameters, the vacuum quality, and the surface contamination of the sample.

To EBID a nanotube onto a surface, magnify the area of interest and scan it for a few minutes. The nanotube should become less visible (as the edges become less crisp), as it becomes replaced by the EBID layer. If the SEM has reduced scan size capability, use a smaller scan size to focus solely on the region of interest. This way, you can use a lower scan rate. Or use the spot-mode to apply EBID to a localized area.

Applying Tension to a Multi-walled Nanotube

Once there is a nanotube extending from a probe, you can perform many different experiments. One such experiment involves applying tension to a nanotube. Historically, this has been done using AFM cantilevers to measure the tensile strength of individual nanotubes.

Materials List

- MWNT: Mount a multi-walled nanotube on a probe, as instructed in “Attaching a Multi-walled Nanotube to a NanoEffector Probe” on page 55.
- Probes: Depending on the experiment desired, you may use AFM cantilevered probes or sharpened metal wires such as tungsten. Zyvex NanoEffector probes are included in the Probe Starter Kit.

1. Yu, M-F, et al., Science 287, 637-640 (2000).

Procedure

Following the general method outlined in “Attaching a Multi-walled Nanotube to a NanoEffector Probe” on page 55, to attach both ends of the nanotube to opposing probe tips, and complete the following steps, as appropriate.

To apply tension to a multi-walled nanotube:

1. Use the fine axis to increase the distance between the probe tips.
2. If you are using straight wires for the approach, use the Y-axis positioners to apply the tension. You may apply a buckling force by reversing the direction of motion. Measure the length by reference annotation.
3. If you are using AFM cantilevers, the working end of the probe is almost perpendicular to the cantilever arm; therefore, you are using the X-axis fine positioner to apply the tension. If you know the force constant of the cantilever, you can measure the displacement by using referenced annotation and computing the Young’s modulus of the nanotube. See Reference [1] for further information and details.

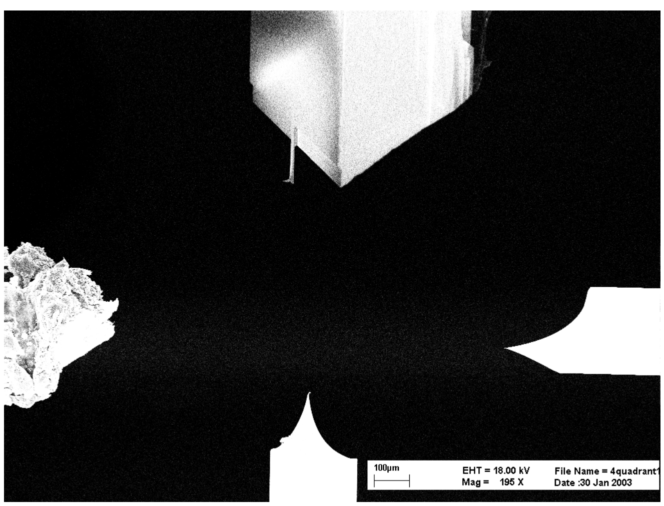


Figure 2: Micrograph of possible configuration showing CNTs, AFM, and probes

Resonating a Multi-walled Nanotube

You can learn the mechanical and electrical properties of nanotubes and other nanowires by their resonance response. For information on the physics, please see Reference [2].

1. Yu, M-F, et al., Science 287, 637-640 (2000).
2. Yu. M-F, et al., Phys Rev B 66, 073406 (2002).

Materials List

When resonating a thin structure, the base of the structure should be rigid or fixed. A thin wire will not provide a rigid enough base. Therefore, you should use a dull probe when performing resonance experiments.

- MWNT: Mount a multi-walled nanotube on a probe, as instructed in "Attaching a Multi-walled Nanotube to a NanoEffector Probe" on page 55. The nanotube should protrude from the probe so that the probe acts as both an anchor and as an AC path.
- Function Generator: Use this to apply an AC signal to the nanotube.
- Oscilloscope: Use this to measure the output frequency and amplitude of the AC signal to the nanotube. You can use this to measure the output frequency and amplitude of the function generator AC signal. This is optional and depends on the reliability of the function generator.
- BNC Cables: Use these to connect the function generator to the oscilloscope and the nanomanipulator system cabinet.
- BNC T-Connector: If using the oscilloscope, this enables sending the signal to both the scope and the nanomanipulator probe.

Procedure

To resonate a nanotube:

1. Set up the nanomanipulator system so that it will be easy to approach the nanotube-tipped probe with an opposing probe.
2. Bring the SEM to vacuum.
3. Wire the function generator between the two probes, using a BNC T-connector from the output of the function generator to the oscilloscope and to the probe with which the AC voltage will be supplied (actuator probe).
4. Approach the target probe with the actuator probe, leaving a distance of up to 1 micron, as shown by the SEM's scalebar.
5. Activate the AC signal.

6 The nanotube will respond only at particular activation thresholds and frequencies, the values of which depend on the diameter and length of the nanotube.

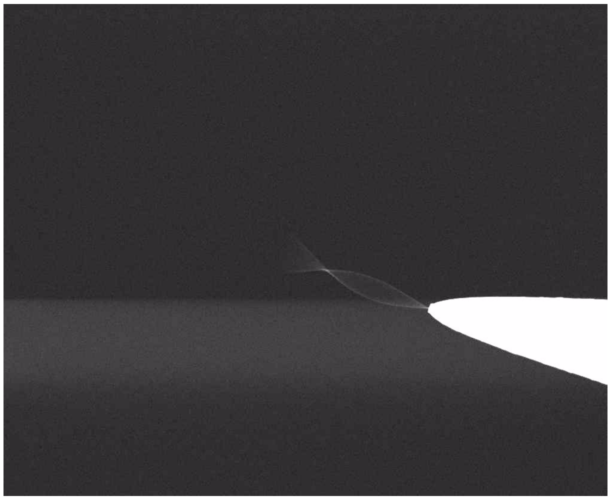
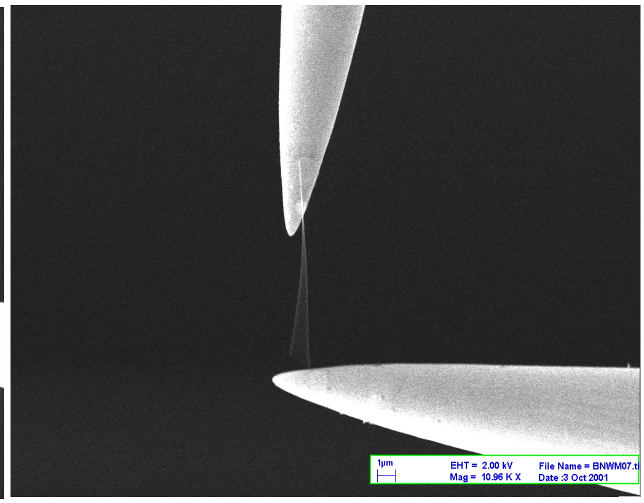



Figure 3: Resonating a nanotube

Note: A more advanced step would be to damp the CNT oscillation using a third probe. The first two probes should be relatively dull, but the third should be sharp. Contact the CNT with the third probe, and record the change in resonance response frequency. In addition, you can observe how the frequency changes as the probe contacts different parts of the CNT.

7 Activate an AC signal while in contact with the CNT.

8 The frequency response will change depending upon where you contact the nanotube because its effective length changes.

9 Slide the third probe along the length of the nanotube with the fine positioner.

10 There should be a change in frequency response.

Probing Transistors at the Contact Level in Integrated Circuits

Probing integrated circuits (IC) with sharp metal contact wires under an optical microscope has been, for many years, the primary means of characterizing an IC's electrical performance. Since advances in IC technology follow Moore's Law of decreasing scale, the complexity of producing and testing the more advanced IC's has increased. More powerful microscopes and highly precise probe placement is needed in order to test these next-generation ICs.

Materials List

The nanomanipulator system is capable of landing four sharp probes easily within a 200 x 200 nm area with less than 5 nm precision. The size of the minimum landing area is dependent on the sharpness of the probes. With Zyvex NanoEffector probes, the minimum landing area could be much smaller than that stated above.

- Keithley 4200 Semiconductor Characterization System
- Keithley Interactive Test Environment (KITE) program on the 4200 to run the “4-point” probe
- Adapter (Keithley’s #237-BNC-TRX) between the coaxial cable on Zyvex test head and the triaxial on the Keithley 4200. The signal lines of the coax and triax cables should be tied together, and the shields should be tied to each other. The guard of the triax is left open.
- IC device
- Zyvex NanoEffector probes 2 mm long from tip to the back of the probe, with a 45 degree bend.

Procedure

The IC test chip should be deprocessed to the contact level and etched for five seconds in 20 parts H_2O to 1 part 49% HF. A high-resolution SEM is ideal for this experiment.

To position the probes:

1. Mount the IC to the grounded center rotational stage.
2. Pump down SEM and determine the microscope image parameters.
3. Position the probes above the test area.
4. Move the probes towards the IC surface and establish probe-to-surface contact.

To probe the IC:

1. Once the probes are in position, life probes just above the surface and move parallel to the surface until each probe is relocated above its intended circuit contact.
2. Sweep probe back and forth to determine the contact and its location.
3. Once the probe makes contact, the probe’s sweeping motion becomes a pivoting motion with the pivot point at the location where the probe touched the IC surface.

4 Position the probe so that the pivot point coincides with the IC device contact. Figure 4 shows four probes in electrical contact with the drain, source, gate, and P substrate contacts of an n-channel MOSFET device.

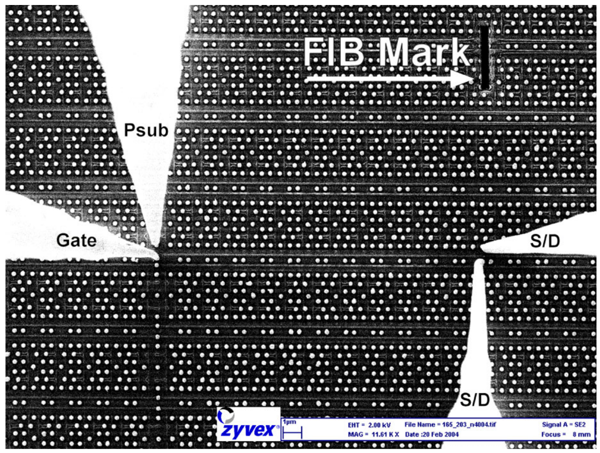


Figure 4: Four probe contact on an n-channel MOSFET. The Gate probe is connected to the pass-gate shared by four n-channel transistors. The Psub probe is connected to the substrate contact and the S/D probes are connected to the source and drain of the transistor being tested.

5 Use the Keithley 4200 Semiconductor Characterization System to bias the probes and collect the IC device drain current vs. drain source voltage ($I_D V_{DS}$) data.

Note: Before and during data acquisition, the microscope's scanning beam was blanked to minimize any charge-induced influence.

Measuring Electrical Breakdown of Dielectric-Filled Trench of Semiconductor Devices

Semiconductor devices employ insulating dielectric materials for electrical isolation between active elements and layers that are susceptible to electrical breakdown. The breakdown voltage is the level at which the insulating dielectric begins to allow charge flow.

Materials List

- Semiconductor device
- Zyvex NanoEffector probes
- Double-sided conducting tape or silver paint. The sample must be conducting and must be held at ground potential.

Procedure

To properly gauge breakdown voltage, you must eliminate alternative paths for current to flow. The current must be a strict measure of the charge flow caused by the applied field across the dielectric. When contacting the surface, simply touching the contact pads, electrodes, or dielectric surface may not be sufficient to pass current (due to contact resistance). To ensure contact, apply the probes onto the contact area with enough force to make them rub against the surface.

If possible, perform this experiment in a clean room to eliminate dust, control humidity, and prevent contaminants from building up on the devices. A SEM is highly recommended for this experiment because the vacuum environment minimizes moisture. It also allows the material to be imaged to ascertain damaged areas and perform a failure analysis *in situ*.

To measure the electrical breakdown:

1. Position the probes into contact wit the device.
2. Turn off the electron beam and positioner motors to reduce noise and charging effects. If repositioning is necessary, repeat the steps above.
3. Perform a voltage sweep across the device.
4. Plot the current versus voltage as the voltage is swept through a predetermined range. Keep in mind that the range and sweep rate of the voltage sweep depends on the dielectric.

Powering MEMS Devices Using the Nanomanipulator System

The ability to power MEMS devices inside a scanning electron microscope (SEM) is a featured application of the Nanomanipulator System. This functionality enables greater characterization of MEMS devices than existing alternative methods. While many researchers have examined the performance of MEMS devices in ambient conditions, very little has been done in vacuum. Because MEMS devices often operate in hermetically sealed packages, characterizing their properties in vacuum presents a more accurate representation of the device properties in the field.

Complex MEMS structures require at least two probes, while most active electronic components such as transistors require at least three probes for in situ testing.

Measuring Voltage and Current

Voltage and current can be monitored using a 2-channel oscilloscope as shown in Figure 5. The current is measured across a resistor of known value. The voltage is measured on another channel of the oscilloscope. It is shown that quadrant "positioners" 4 and 1 are used in the experiment to drive the actuator. This will vary depending on which quadrant is in use to power the device.

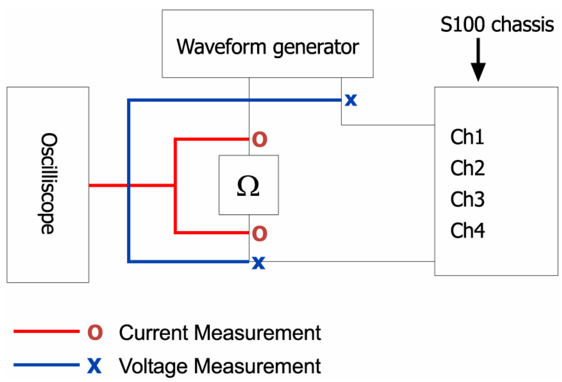


Figure 5: Power data collection set-up

Experimental Set-up for Powering MEMS

An electrothermal actuator can be powered in the SEM using the nanomanipulator system. You must be careful to track which positioner is being powered, and which pin associated with that positioner is connected to the probe.

It is good practice to make note of the probe positions for all quadrants before placing the system in the SEM. But sometimes it is not obvious which quadrant will be best for powering the device until the system is in the SEM, and the image is in view. In such cases, the powered probe can be identified by applying a square wave with a voltage greater than 1V. This will cause the contrast to change and the probe will change contrast with the signal.

The Power Data Collection set-up shown in Figure 5 is connected to the system's patch panel.

Powering a Device

The power on and off positions can be captured in the SEM, giving a double exposure effect which makes it useful for taking measurements. The SEM was put into an averaging mode to create this effect. Videos of the device were also taken. Various useful measurements can be taken using the SEM tools. Figure 6 shows the electrothermal actuator designed with the on and off states superimposed in one image. This actuator was powered with a 15 V peak to peak square

wave to minimize the time between the on and off states of the device. It was noticed that one state (on or off) was brighter than the other. By modifying the duty cycle of the input signal the contrast can be adjusted so that both states have the same brightness. In this example, the driving frequency was varied between 5Hz and 30Hz and adjusted manually until the on and off position of the actuator could be clearly seen on the screen.

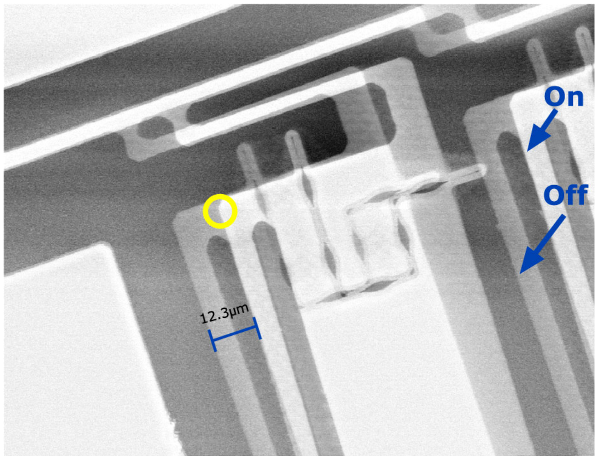


Figure 6: Electrothermal ganged bimorph actuator

Observing Backlash/Creep

Backlash has been observed while the device is in the powered (forward moving) state. This is shown with the zoom view of the edge of the device (See Figure 6). The device overshoots slightly at first and the backlash is observed as the device moves backwards. Creep can be observed if the device moves slowly while being powered by a DC signal. The amount of creep can be measured using the measure tool in the SEM.

Measuring Plastic Deformation

The MUMPS bimorph shown in Figure 7 has been purposely overdriven and the resulting plastic deformation is shown in Figure 8. The two pictures in Figure 8 show the plastically deformed overdriven condition. It is observed that the final rest position of the bimorph is now several microns backwards based on the vernier scale. The SEM measure tool can also be used to quantify the displacement. This is demonstrated by comparing the bottom two images in Figure 8. This plastic deformation of the bimorph does not reduce the total range of motion of the bimorph.

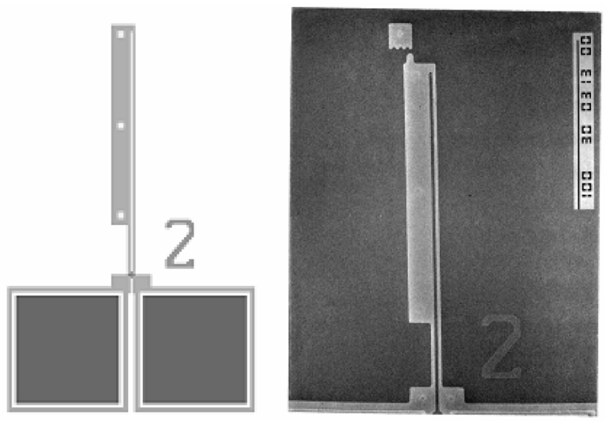


Figure 7: SEM image MUMPS bimorph

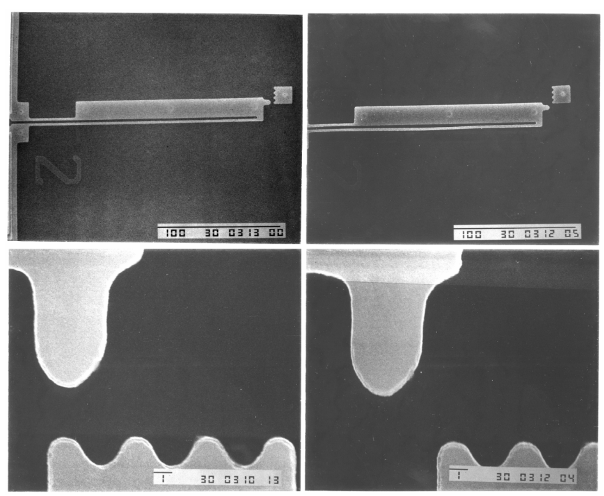


Figure 8: Before and after overdriving the actuator

Square waves of sufficient amplitude drive the thermal bimorph about its equilibrium position. Figure 9 shows a 2 micron bimorph driven by a 358 Hz square wave with a 2 Volt amplitude. The driving frequency was chosen so that the image could easily record the two extreme positions of the thermal bimorph's motion. The leftmost position of the thermal bimorph corresponds to the voltage off position. In Figure 9, the off position is different from the fabricated position, probably due to the higher thermal mass of the cold arm. When driving the bimorph with a square wave, both the hot arm and the cold arm reach a steady state temperature distribution if the length of the square wave pulse exceeds the thermal time constant of the actuator. When the voltage returns to zero, the hot arm cools down faster than the cold arm since it has less thermal mass. The cold arm also takes longer than the hot arm during the power off part of the square wave cycle. This produces motion about the power off equilibrium position.

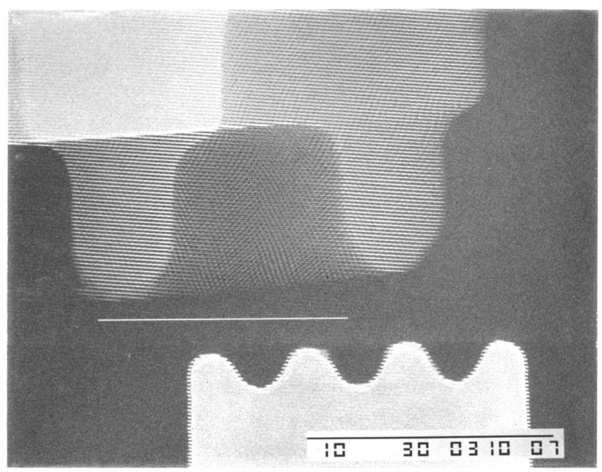


Figure 9: Thermal bimorph (358Hz)

Lifetime Measurements/Analysis

Extended testing of the thermal bimorphs showed that they could be operated for long periods of time under the appropriate conditions. Figure 10 shows two images of a 2 micron thermal bimorph in the power off position. The image on the left was taken prior to operation. The image on the right was taken after the thermal bimorph had completed about 30 million cycles. The driving frequency during the test was approximately 357 Hz and the amplitude of the square wave was about 1.5 volts. No difference can be seen in the equilibrium position.

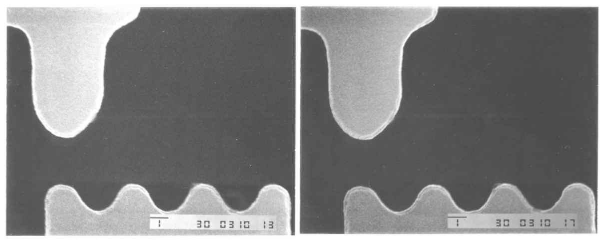


Figure 10: Before and after lifetime testing

Qualitative data regarding the performance of MUMPS thermal bimorphs has been obtained by testing several thermal bimorphs from three different dies. The current versus displacement is easily measured. This is done by measuring the voltage across the resistor as shown in Figure 1. The voltage is divided by the resistance value of the resistor used. The displacement is measured using the SEM measure tool. Current, voltage and resistance versus displacement can be taken with the set-up shown in Figure 5.

Dynamic Behavior Measurements

Dynamic behavior was measured by sweeping the frequency of 1 volt peak to peak sine wave from zero to 120kHz. The dynamic behavior of thermal bimorph actuators operating in vacuum is of interest for determining the maximum operating frequency of the actuator. The thermal time constant of the device determines the maximum operating frequency independent of the resonant frequency. This time constant is a measure of the time required for the actuator to cool down after actuation. For ambient operation, heat transfer out of the device can be convective through the surrounding air, and conductive through the anchors connecting the actuator to the substrate. In vacuum the heat transfer only occurs via conduction and radiation; thus the thermal time constant in vacuum should be longer and the maximum operational frequency should be lower. This was confirmed from the data obtained.

Powering an Electrostatic Actuator in SEM

Electrostatic devices require higher voltage than electrothermal devices (between 40V and 150V). Therefore some external amplifiers are required to boost the signal. The power was monitored in a similar fashion as shown above in Figure 5. Again the contrast of the image was modified (on an off states) by adjusting the duty cycle on the square wave signal from the signal generator.

Powering an Electrothermal Hula Actuator in SEM

The electrothermal "hula" actuator has been tested in the SEM because this device actually changes form after it has been powered. The pictures show distinct before and after orientation in Figure 11 (before) and in Figure 12 (after). The device plastically deforms and retains its shape after it has been powered. This device has been specifically designed utilizing the mismatch in thermal expansion coefficient of metal and polysilicon to bend the structure out of plane like an accordion. The "before and after" actuation pictures of the device can be taken at one time in the SEM due to the ability to power MEMS devices in the SEM.

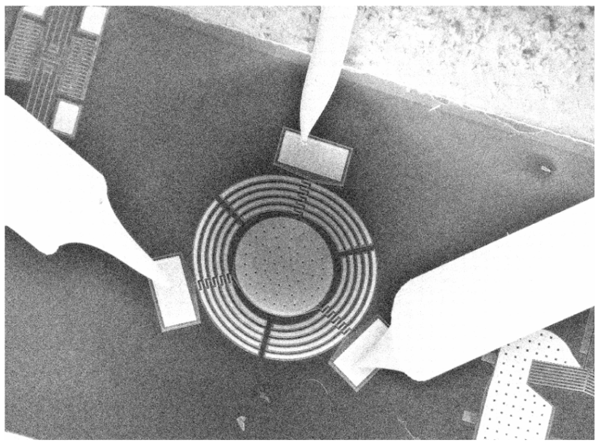


Figure 11: Hula Actuator before power is applied

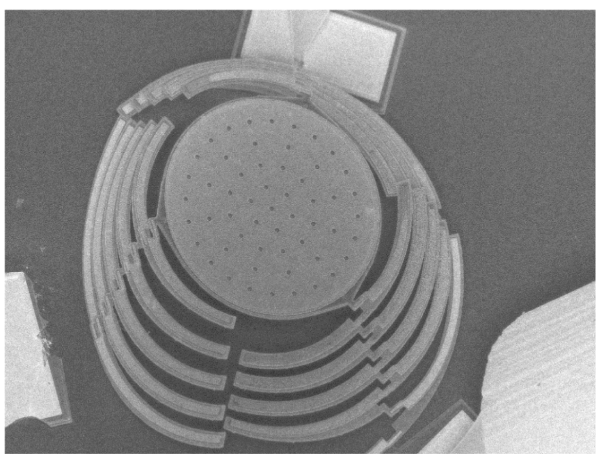


Figure 12: Hula Actuator after power is applied

Chapter 10: User-level Calibration

Understanding and Using Slip Stick Motion

The extended range positioning system of the Nanomanipulator System uses Slip-Stick Motion for nanomanipulation. It is important to understand the difference between true stepper motion and slip stick motion.

Stepper Motion Versus Slip Stick Motion

Motors convert electrical energy into mechanical energy. The movement created by electrical pulses in a stepper motor is precise and repeatable. Permanent Magnet stepper motors incorporate a permanent magnet rotor, coil windings, and magnetically conductive stators.

Energizing a coil winding creates an electromagnetic field. The stator carries the magnetic field which causes the rotor to align itself with the magnetic field. By applying pulsed electrical signals to the stator, rotary motion is generated. A stepper will typically be within 0.5° (or a specific number of degrees according to manufacturer's specifications) of theoretical position for every step. The errors are not cumulative because the mechanical design of the motor dictates a 360° movement for each revolution.

Slip Stick Motion Drives (SLDs) (or inertial drives) use the difference between static and kinetic friction to move a slider by stepping through slipping and sticking cycles. Sliding starts when the exerted force exceeds the static friction. Piezo actuators are used to exert the high accelerations needed to force the transition from sticking to sliding

SLDs are frequently used in nano positioning applications because of their small step sizes, high mechanical stability and robustness, device simplicity, and the compatibility with vacuum and cryogenic environments. SLDs also have several disadvantages, such as uneven steps, vibrations, and poorly reproducible step size.

Static and Kinetic friction vary significantly with surface roughness and lubrication. Thin water layers, often found on surfaces exposed to the atmosphere, also have lubricating properties.

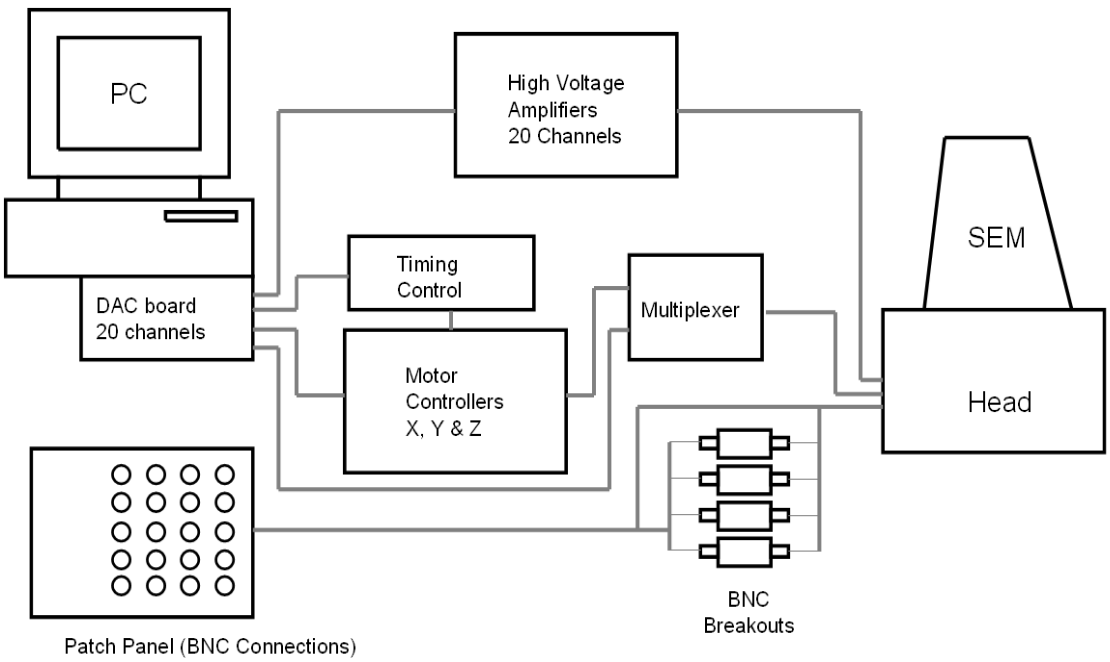
True stepper motion is more accurate than SLDs in the sense that errors in the step size of a stepper motor do not accumulate. This must be kept in mind when evaluating and understanding the step sizes of the Nanomanipulator System's extended range positioning. On the small scale that the head works on, the friction may vary significantly from step to step. The numbers that are obtained for step size should be used as an estimate, or a guideline. Relying on a counted number of steps is not sufficient to determine the exact position of a probe relative to a surface or substrate.

Optimizing Values for the Extended Range Positioners

Once you have an image of the probe or probes on screen, you can optimize the values for the extended range positioners using the procedure in Chapter 8: "To configure the Extended Range (Coarse) Axis Deflection."

Chapter 11: Schematics

Block Diagram



Chapter 12: Troubleshooting and Obtaining Zyvex Support

This chapter can help you troubleshoot minor problems that you might encounter as you use the any of the Nanomanipulator Systems. You can also obtain further help from Zyvex support.

Troubleshooting

Problem	Possible Meaning(s)	Possible Solution(s)	Further Help
The piezos do not move on the head assembly.	• The motion is maxed out. • The feedthrough connector is not plugged in. • The power supply is not working.	• Try moving the piezos in the opposite direction. • Turn off the power, and then check that the feedthrough connectors are properly connected. • Check the power supply rack and be sure that the LEDs are on.	**Contact Zyvex Support at tools.support@zyvex.com.**
The rotational sample stage is not turning on the system.	• The power to the rotational stage may not be connected. • There may not be enough signal to actuate the rotational stage. • There may be an object obstructing it.	• Check the power supply rack and be sure that the LEDs are on. • Check the % output in the Setup menu and try increasing it. If you get to 100%, and there is still no actuation, contact Zyvex. • Visually inspect the rotational sample stage, and check that the sample itself is not obstructing the motion.	
Current is not flowing to your NanoEffector.	The wrong probe may be selected.	Check to see which probe you should be contacting. You can do this using a voltmeter, or by visually inspecting the NanoEffector plugs and the position of your NanoEffector.	

Problem	Possible Meaning(s)	Possible Solution(s)	Further Help
An alarm has sounded on the SEM or dual-beam FIB equipment, or your screen is displaying a ground shortage warning message.	A short has occurred between the chamber's ground and earth ground.	Some UHV equipment have a dedicated sample ground. If this contacts the chamber ground, you may hear or see warnings, depending on your equipment. • Visibly verify that the wiring harness inside the vacuum is not contacting the stage or the system head. • Check that the green wire outside of the chamber is not touching the chamber.	**Contact Zyvex Support at tools.support@zyvex.com.**
+22/-22V LED on the Power Supply Rack is not lit.	• Fuse is blown • Power is not on	• Check the 1.2 A fuses and the 1.5A fuse • Check that the power supply is on	
+220/-250V LED on the Power Supply Rack is not lit.	• Fuse is blown. • Power is not on.	• Check the 0.1A fuses and the 0.75A fuse. • Check that the power supply is on.	
+48V LED on the Power Supply Rack is not lit.	• Fuse is blown. • Power is not on.	• Check the 3.0A fuses. • Check that the power supply is on.	
The Fan in the cabinet is not turning.	• Fuse is blown. • Cabinet is not plugged in.	• Check the 1.0A fuse. • Check that the cabinet is plugged in.	

Obtaining Additional Zyvex Support and Training

To learn about additional support programs and training in using the Nanomanipulator Systems, please contact Zyvex.

Chapter 13: Spares, Consumables, and Optional Equipment

For preventive maintenance, Zyvex suggests purchasing recommended spares and consumables for the Nanomanipulator System. To purchase recommended spares and consumables or to learn about optional equipment, please contact Zyvex.

Spares and Consumables

Fuses	Quantity	Check the Fuse If . . .
Fuse 1.2 A	2	The +22V/-22V LEDs on the power supply rack are not ON.
Fuse 0.1 A	2	The +250V/-250V LEDs on the power supply rack are not ON.
Fuse 3.0 A	2	The +48V LEDs on the power supply rack are not ON.
Fuse 0.75 A	2	The +250V/-250V LEDs on the power supply rack are not ON.
Fuse 1.0 A	1	The fan in the cabinet is not turning.
Fuse 1.5 A	1	The +22V/-22V LED on the power supply rack is not ON.

Note: All fuses are located at the back of power supply rack

Figure 1: Front view of the Power Supply Rack

Optional Equipment

- NanoEffector plugs
- Five-channel, fine-positioning amplifier
- Extended Range positioner amplifier